MARINE AND NAVAL BOILERS

1920


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MARINE AND NAVAL BOILERS

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BY

LIEUT. COMMANDER FRANK LYON, U. S. NAVY

AND

LIEUT. COMMANDER A. W. HINDS, U. S. NAVY

REVISED BY

LIEUTENANTS W. P. BEEHLER AND JOHN S. BARLEON, U. S. NAVY

Of the Department of Marine Engineering and Naval Construction, U. S. Naval Academy, under the supervision of the Head of the Department

THIRD EDITION REVISED BY

COMMANDER W. L. FRIEDELL, U. S. NAVY

Of the Department of Marine Engineering and Naval Construction U. S. Naval Academy, under the supervision of the Head of the Department

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PREFACE.

The "Text-Book on Naval Boilers," by the late Captain F. C. Bieg, U. S. N., has been in continuous use at the United States Naval Academy for the instruction of midshipmen since 1903. This book was one of the best, for its purpose, ever produced at the Academy. The advances in the last few years, however, both in the art of boiler construction and management and in the use of liquid fuel, made imperative either a very thorough revision of Bieg or a new text-book giving the latest information on the subject. It was unfortunate for the midshipmen and for the naval service that the death of Captain Bieg caused the work of revision of the boiler text-book to fall on the shoulders of others.

Early in the fall of 1910, at the request of the head of Department of Marine Engineering and Naval Construction, United States Naval Academy, the revision of Bieg was undertaken by Lieutenant Commander Frank Lyon, United States Navy, who was later joined in the work by Lieutenant Commander A. W. Hinds, United States Navy.

As the revision progressed it was found that, while about one-fourth of the old text could be used, the rearrangement and different methods of handling the chapters would make the new edition very different in appearance and in contents from the book under revision. For the above reasons, and due to the fact that some of the theories herein advanced may be disputed, it was decided by the revisers to accept the responsibility and publish the new book under their own names. This decision was referred to and concurred in by the Board of Control of the United States Naval Institute, the owner of the copyrights of the old book.

The chapter on "Corrosion" is the result of studies and experiments conducted by Lieutenant Commander Lyon during 1909, 1910 and 1911.

Sincere thanks are extended to Rear Admiral H. I. Cone, Engineer-in-Chief, United States Navy, and to his assistants, as well as to the manufacturers of the various types of boilers, fittings and accessories, for their uniform courtesy and valuable help.

Grateful acknowledgment is made to the American Society of Naval Engineers, and to Commander U. T. Holmes, United States Navy, author of "Experimental Engineering," for their generosity in allowing the use of both subject matter and cuts.

Thanks are due to Commander M. E. Reed, United States Navy, head of the School of Marine Engineering, and to the students at that school for assistance given by criticising the manuscript before sending it to print.

FRANK LYON,
A. W. HINDS,
Lieut. Commanders, U. S. Navy.

UNITED STATES NAVAL ACADEMY,
ANNAPOLIS, MD., JANUARY, 1912.

In the preparation of this book many other text-books and publications have been consulted, among which are:

Text-Book on Naval Boilers. F. C. Bieg.

Steam Boiler Economy. Kent.

Journal of the American Society of Naval Engineers.

Machinery Specifications for U. S. Naval Vessels.

Annual Report of the Chief of the Bureau of Steam Engineering.

Journal of the American Society of Mechanical Engineers.

Report of the Liquid Fuel Board.

Marine Boiler Management and Construction. C. E. Stromeyer.

Steam Boilers. C. H. Peabody and E. F. Miller.

Marine Boilers. L. E. Bertin: L. R. Robertson's edition and translation.

Corrosion and Preservation of Iron and Steel. Cushman and Gardner.

Marine Steam by the Babcock & Wilcox Co.

Steam Boiler. Fowler.

Power and the Engineer.

Steamship.

Jones' Physical Chemistry.

Circulars of Makers of Boiler Fittings and Accessories.

PREFACE TO SECOND EDITION.

The work of revision of the excellent book on Marine and Naval Boilers, by Lieutenant Commanders Frank Lyons and A. W. Hinds, was undertaken at the request of the U. S. Naval Institute, because the original edition was sold out and it was deemed advisable to take advantage of the opportunity to bring the book up to date in every respect. The largest part of the work of revision consisted in the elimination of those types of boilers and accessories which have become obsolete, and the substitution of the latest designs and types installed in the U. S. Navy.

As this book is intended primarily for the use of midshipmen at the Naval Academy, a large part of it is necessarily devoted to details of construction, to the exclusion of the theory of boiler design. The theory of heat transfer, while of the utmost importance in the intelligent operation and management of boilers, is treated in a very general way because of lack of space, and on account of the omission of the study of technical thermodynamics from the curriculum. The discussion of combustion is also necessarily brief for the same reasons.

The chapter on " Corrosion " as originally written by Commander Lyon was found to be too involved for the use of midshipmen, and it was considered necessary to omit most of the theory of corrosion and to substitute therefor a short discussion of experimental results, and of the practical methods of preventing corrosion. The elimination of the theory does not indicate that a knowledge of such theory is undesirable and for a thorough knowledge of this subject the student is referred to the many good treatises recently published.

The revisers desire to express their sincere thanks to Lieutenant G. S. Bryan, U. S. N., for assistance in the preparation of the chapter on " Corrosion "; to the officers of the Bureau of Steam Engineering, Navy Department, for their kind assistance in furnishing information and blue prints; to the J. A. S. N. E. for the use of subject matter and of the plate of " Temperature—Viscosity Curves "; to Mr. F. H. Rittenour for the tracings used in making

some of the plates, and to the several manufacturers who furnished subject matter and blue prints for some of the cuts and plates.

Special thanks are due to Commander H. B. Price, U. S. Navy, Head of the Department of M. E. & N. C., for his helpful suggestions and criticisms, while supervising the work of revision.

W. P. BEEHLER,
Lieutenant, U. S. Navy,
JOHN S. BARLEON,
Lieutenant (J. G.), U. S. Navy.

PREFACE TO THIRD EDITION.

The revision of this book was undertaken at the request of the U. S. Naval Institute. The second edition having been sold out, it was deemed advisable to take advantage of the opportunity presented to revise the book before printing another edition.

This revision consists primarily in eliminating obsolete types and substituting more modern ones in their place. A few corrections have been made.

The reviser desires to express his thanks to the officers and instructors of the Department of Marine Engineering and Naval Construction for their assistance with helpful suggestions and criticisms.

W. L. FRIEDELL,
Commander, U. S. Navy.

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CHAPTER I.

DEFINITIONS, PRINCIPLES AND TYPES.

A **steam boiler** is a vessel in which, by the agency of heat derived from the combustion of fuel, water is converted into steam; and in which the steam is raised to the temperature and pressure required for use as the prime mover of machinery. A marine steam boiler is one adapted for use on board ships.*

Coal is the fuel in most general use in marine boilers.

Many marine boilers are now fitted to burn either liquid fuel alone, coal and liquid fuel at the same time or coal or liquid fuel separately in the same furnace. In the United States Navy all new battleships have their boilers fitted to burn either coal or liquid fuel alone or both at the same time; all new destroyers are fitted to burn liquid fuel only. The latest battleships contracted for are to burn liquid fuel only.

The energy released by the combustion of the fuel is transferred through the heating surfaces to the water in the boiler, converting it into steam, and raising the steam and water to the temperature that gives the required pressure. The steam is then led from the boiler through pipes and valves to the various engines, where its heat is converted into mechanical energy for use direct, or for conversion into the electrical, hydraulic or pneumatic energies, which are now used to a great extent in all classes of naval vessels.

Heating surfaces are all the metallic surfaces that transmit heat from the flames or gases of combustion to the water. They consist of the surfaces in contact with flame or gases of combustion, on one side, and of all the water-containing parts of the boiler, on the other, from the level of the grate bars to the water line in the steam drum. The superheating surfaces are all those surfaces in contact with flame or gases of combustion, on one side, and steam on the other.

In all cases of measuring the heating or superheating surfaces of a boiler, those to be measured are the surfaces in contact with the flame or gases of combustion, and not those in contact with the

* "Kent's Steam Boiler Economy."

water and steam, as, for instance, the inside diameter of a fire tube and the outside diameter of a water tube.

The general requirements of a good marine boiler are that it should be designed so that it may have:

1. The maximum heating surface in proportion to its weight.

2. The maximum strength with minimum thickness and weight of material.

3. The maximum strength due to its form without artificial support.

4. The maximum resistance of its component materials to corrosion and erosion.

5. The maximum circulation of its contained water.

6. The maximum circulation of the hot gases of combustion in contact with its heating surfaces.

7. The maximum transference of heat per unit of the heating surface.

8. The minimum weight in proportion to steaming power.

9. The minimum of fuel consumed per effective horse-power.

10. The minimum of water delivered with the steam.

11. The minimum of heat delivered to the atmosphere.

Marine boilers are divided into two general classes: (1) *Fire-tube boilers,* (2) *water-tube boilers.*

Fire-Tube Boilers.—The boilers of this class have a relatively large quantity of water contained in a closed tank or shell. This shell also encloses the furnace, in which the fuel is burnt; the combustion chamber, in which the volatile combustible matter is consumed; and the tubes, through which the heated gases of combustion are passed on their way from the combustion chamber to the uptake. Different authorities use various names for this class of boilers, such as *Scotch, shell, tank, tubular* or *fire-tube boilers;* the name used throughout this book will be *fire-tube boilers,* for the reason that the hot gases of combustion pass *through* the tubes. The tubes in all cases are surrounded by the water contained in the shell.

A fire-tube boiler may be (1) a *return fire-tube boiler,* or (2) a *direct fire-tube boiler.*

(1) The **return fire-tube boiler** is one in which the gases of combustion pass to the uptakes from the upper part of the combustion chamber, through tubes, over the furnace in which the fuel is consumed. They may be either single-ended or double-ended; that

is, they may have furnaces, combustion chambers and tubes in one end only or in both ends.

(2) The **direct fire-tube boiler** is one in which the gases of combustion pass from the combustion chamber to the uptakes through tubes placed in the end of the boiler opposite to that in which the furnace is placed. There are two types of direct fire-tube boilers—the *gunboat* type and the *locomotive* type.

In the **gunboat** type the volatile combustible constituents of the fuel are consumed in a combustion chamber placed at the inner end of the furnace; in the **locomotive** type the gases are consumed in an enlarged space directly over and forming an integral part of the furnace.

More detailed descriptions of fire-tube boilers will come in Chapter II.

Water-Tube Boilers.—Boilers of this class have a relatively small quantity of water enclosed in drums, connected by tubes, *around* which the gases of combustion are passed on their way from the enclosed furnace, at the base of the boiler, to the uptake. These boilers are also called *tubulous boilers,* but the name employed throughout this book will be *water-tube boilers,* for the reason that the water to be heated passes through the tubes.

Water-tube boilers are generally known by the names of their inventors.

Classification of Water-Tube Boilers.—They are classified in several different ways—one with regard to size of the tubes, one with regard to whether the upper ends of the tubes enter the steam drum in the steam space or in the water space, and one with regard to steam and water circulation.

Size of Water Tubes.—All water-tube boilers are of either the *large-tube* or the *small-tube* type; those having tubes 2", or larger, outside diameter, are of the large-tube type; those with tubes of less than 2" outside diameter are of the small-tube type.

Small-tube boilers, which have a very large amount of heating surface made up of many small, thin tubes, are said to be of the *express* type. The Babcock & Wilcox boiler is the most familiar example of the large-tube type; the Thornycroft, of the small-tube type; and the Normand, of the express type.

Above-Water and Drowned-Tube Boilers.—Water-tube boilers in which the upper ends of the circulating tubes enter the steam space of the steam drum, are known as *above-water* or *non-reversible*

cycle boilers; non-reversible, as the steam and water can only flow one way. The best examples of these are the early Thornycroft and Mosher boilers. When the tubes enter the water space of the steam drum they are *drowned-tube,* or *reversible-cycle boilers;* reversible cycle, because the water and steam can flow either way. The best known examples of this type are the Yarrow, Normand, White-Forster and Stirling. The above-water type is now obsolete, but the drowned-tube boiler is in general use.

Circulation.—Classed as to circulation, all water-tube boilers are of one of the following types:

(a) Boilers with *limited circulation.*

(b) Boilers with *free circulation.*

(c) Boilers with *accelerated circulation.*

(d) Boilers with *forced circulation.*

(a) Boilers with **limited circulation** have tubes of coil or serpentine form inclined to the horizontal; sometimes they have only a single tube of helical shape surrounding the furnace. There is no circulation except that necessary to replace the water evaporated. The water enters the tubes at the lower end and discharges from the other end as steam into the steam drum. There are no vertical legs by which the steam bubbles can escape freely into the drum; they must travel in the inclined tube through the stagnant water.

(b) Boilers with **free circulation** comprise those in which the slightly inclined or nearly horizontal tubes extend between vertical flat-water spaces or headers at the front and back or on the sides, or those that have nearly horizontal Field tubes.*

These tubes receive their water from one reservoir and discharge it into the other as steam, or as a mixture of steam and water. The water and steam both travel in the tubes and are free to rise at the vertical headers.

(c) Boilers with **accelerated circulation** comprise those with horizontal drums or reservoirs placed at different heights connected by vertical or nearly vertical tubes; and those having nearly vertical Field tubes. Boilers with accelerated circulation are characterized by the direction given to the water, which is as nearly vertical as possible in its passage between the drums. Large down-comer tubes, or, in some cases, the rows of tubes away from the fire, return the water from the steam drum to the lower drums. Everything is arranged to facilitate a continuous and general circulation.

* A Field tube is a tube consisting of an inner or *circulating* tube and an outer or *generating* tube.

(d) Boilers with **forced circulation** comprise those in which circulation is stimulated by pumping feed water through the boiler. They are not used for naval purposes.

Comparison of Fire-Tube and Water-Tube Boilers.—Aside from the material difference in construction of fire-tube and water-tube boilers, they each have their advantages and disadvantages for marine work.

The advantages of the fire-tube boiler are: (1) Owing to the large volume of heated water in these boilers and the large steam space, they answer to fluctuations in speed with slight attention to fires; (2) the furnace being enclosed in the shell, there is a smaller radiation loss from the furnace; (3) there are fewer joints to keep tight; (4) less attention is required to water-tending; (5) there is less danger from using salt or impure feed; (6) they are easier to examine and clean.

The advantages of the water-tube boiler are: (1) Less weight per unit of power generated; (2) less boiler space per unit of power; (3) ease by which they can be removed from or replaced in a ship; (4) less time and care required to get up steam; (5) less danger to life and to the ship from boiler explosion; (6) more units in power installation, so that one boiler out of order decreases total power to a less extent; (7) greater suitability with safety for high pressures; (8) greater ability to stand forcing; (9) less liability to leaks brought about by expansion and contraction.

The following table gives the type of boiler now generally used for the several types of ships, with the pressures and kind of propelling machinery usually employed in the U. S. Navy.

Boiler.	Type of ship.	Engine.	Steam pressure lbs. per sq. in.
Scotch.	Colliers.	Recip. and turb.	100 to 200.
	Gunboats.	Recip.	
	Tugs.	Recip.	
Large-tube water-tube.	Battleships.	Recip. and turb.	175 to 315.
	Large cruisers.	Recip. and turb.	
	Auxiliary vessels.	Recip. and turb.	
Small-tube water-tube.	Destroyers.	Recip. and turb.	250 to 300.
	Small, fast cruisers.	Recip. and turb.	285.
	Battleship.	Electric drive.	
	Battle cruiser.	Electric drive.	

CHAPTER II.

FIRE-TUBE BOILERS.

Fire-tube boilers are not now being installed in any of the armed vessels of the U. S. Navy. When the fire-tube boilers installed in the older armed vessels need extensive repairs, they are generally replaced by water-tube boilers. Some of the newer fleet colliers have water-tube and some fire-tube boilers. The *Neptune* and *Cyclops* have three double-ended return fire-tube boilers and one single-ended return fire-tube boiler; the single-ended boiler is intended mainly for use in port. The *Vulcan* has four single-ended return fire-tube boilers. The colliers *Prometheus* and *Vestal,* built at navy yards, are each fitted with six water-tube boilers. There are only two vessels, the *Castine* and the *Machias,* fitted with locomotive boilers of the direct-tube type, and only a few ships have the gunboat direct-tube type.

In a few more years all armed vessels that now have fire-tube boilers will have had them replaced by water-tube boilers or the vessels will have been scrapped.

Double-Ended Return Fire-Tube Boilers.—Plate I shows two views of a double-ended return fire-tube boiler. Fig. 1 is a front elevation and Fig. 2 a side elevation with the right half in section through the center of the lower right furnace. The boiler is cylindrical, as may be seen from this plate.

The cylinder, closed at each end by a flat head, is called the ***shell.*** Built inside of the shell at each end are four furnaces *F,* each furnace having its own combustion chamber *A,* and nest of tubes *T.* The fuel is placed through furnace doors *Q* on grates *G,* the gases of combustion pass from *F* into *A,* through *T* out of the boiler into front connection *C;* through the uptake *U,* through breeching * (not shown), through smoke-pipe (not shown) to the atmosphere.

When the boiler is ready for steaming, the shell is filled with fresh water to about three inches above the top of *A';* the water then

* The breeching connects the uptakes of several boilers to the common smoke-pipe.

completely surrounds all parts of the boiler in contact with the fire or gases of combustion in F, A and T. The space left above the water, called the *steam space*, collects and contains the steam as it is formed when combustion is taking place in F. Near the top of this space, steam may be drawn for use through slots in the dry pipe D, which connects with the stop-valve W, through an opening cut in the boiler head. By means of W the supply of steam for use can be regulated.

The two furnaces on the right of Plate I, Fig. 1, are shown with the furnace front R, furnace door Q, and ash-pit door P removed. Fuel is placed on the grate G through door Q; and the air necessary for combustion of its volatile combustible gases is admitted over the fire through small holes in R and Q; and that necessary for the combustion of its non-volatile matter, under the fire through semi-circular openings left by removing P. The air finds its way up through the fuel.

The grate G consists of a series of grate bars supported on bearer bars, and it divides the corrugated furnace proper into the furnace F and the ash pit F'. The lower part of F' is covered with an ash pan F''. S is a slicing door in Q for working the fire without opening the door. B is a fire-brick bridge wall built on an iron frame; it makes a back wall for the fire, and slightly reduces the outlet for the gases of combustion as they pass from F to A.

C and U are secured to the outside of the boiler, and are, therefore, not integral parts of it. Access to the interior of C and U, and to the front ends of the tubes T, is obtained through the connection doors V, three of which are shown in place; the fourth one is removed from its hinges and shows the front ends of the tubes. SD are soot doors in the bottom of C, and there are three sliding dampers above V for regulating the draft and rate of combustion. The steam pressure, above the atmospheric pressure, inside the shell, is shown by the steam gage SG, and any excess of pressure above that at which the safety valves Sf are set is relieved by them. The water-gage glasses WG and the gage cocks GC are used to indicate the water level in the shell. K and L are small valves on the water columns connecting WG to the steam and water spaces of the shell. The supply of water to the shell is regulated by means of the feed check-valve and feed stop-valve at E; a pipe connects this with the feed pumps. Access to the interior of the shell is obtained through the manholes M'; three of these are shown closed by the manhole

2

plates *M*. *H* is the surface blow-valve connected to the water in the shell by the internal pipe and scum pan *SP*. A pipe leading from *H* overboard is connected to the bottom blow-valve *J*. *I* is the hydrokineter valve for aiding water circulation when getting up steam; there is one at each end of the boiler.

Z, at the top of the shell, is the air cock, and *DC*, at the bottom, is the drain cock. *Y* is the dynamo stop-valve.

All flat surfaces exposed to pressure must be stayed, braced or otherwise strengthened at regular intervals. The combustion chambers *A* are practically rectangular boxes of thinner plates than the boiler heads, and need much staying and stiffening. The flat heads are tied to each other by the braces *O*, of which there are four horizontal rows above the tubes and three surrounding the lower manholes. Similar braces, but shorter, tie the remaining flat and unbraced parts of the heads to the unbraced parts of the front combustion-chamber plates. The back and side plates of these chambers are stayed to those of the adjoining ones, or to the shell of the boiler, by screwed stay bolts; their flat bottoms are stiffened by three angle irons and their flat tops by the girders *A'*.

The front plate of the combustion chamber is called the *back tube sheet;* the middle plate of the boiler head is called the *front tube sheet.* These tube sheets are tied to each other by the ordinary tubes expanded into each plate, and by the heavier stay tubes screwed into each plate.

The boilers are supported by the saddles *N* built up from the hull of the ship, and are placed in water-tight compartments called *boiler compartments.*

The saddles are generally secured to the shell by means of brackets which are riveted to the shell and bolted to the saddles.

The number of boilers in each compartment depends upon their kind and size, and the size of the ship.

The fire-room is the space left in each compartment at the furnace ends of the boiler, and must be long enough to enable proper handling of firing tools. On board ship, the boiler compartments are called fire-rooms.

The boilers may be placed either fore and aft or athwartships. Communication between boiler compartments is by fire-room passages or doors; the doors are water-tight.

The steam spaces of the boilers are connected through a system of pipes and valves to each other and to the various engines.

The uptakes of a certain nest or number of boilers join in the breeching on top of which is set the smoke-pipe.

The rectangle enclosing the outside limits of the grate is called the *grate surface.*

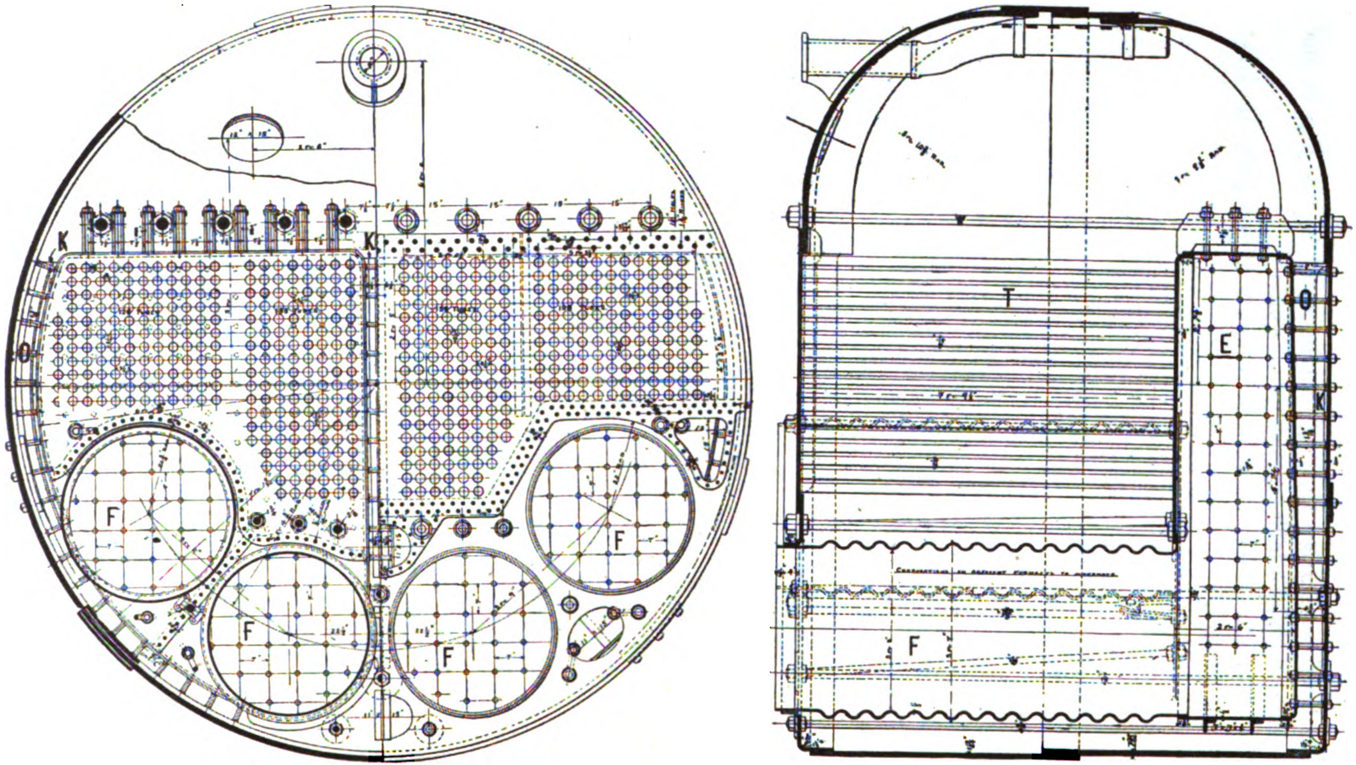


Fig. 1.—Single-Ended Return Fire-Tube Boiler.

Single-Ended Return Fire-Tube Boiler.—Fig. 1 shows two views of a single-ended return fire-tube boiler. The right half of (a) is a front elevation of the boiler, with the connections and uptake removed, and the left half of (a), a section through the middle of the length of the boiler. *FF* are the furnaces, *E* the combustion chamber, one for each furnace, and *T* the tubes. The heads, instead of being flat, as in the double-ended boiler, are bent back at the top. By this construction, the two upper rows of braces become unnecessary, but the steam space is somewhat reduced. (b) is a longitudinal section through the center of the right lower furnace. The manner of staying the combustion chamber sides to each other and to the shell is shown by the screw stays *O, O*. The flat back head of the boiler between adjoining combustion chambers is stayed by T-bars, shown in the sketch, but not lettered.

The front head between adjoining nests of tubes is similarly stayed. The single-ended boiler is heavier and more expensive than the double-ended one for the proportionate heating surface, and its evaporative efficiency is, in practice, generally lower. The remaining parts are similar to those of the double-ended boiler already described.

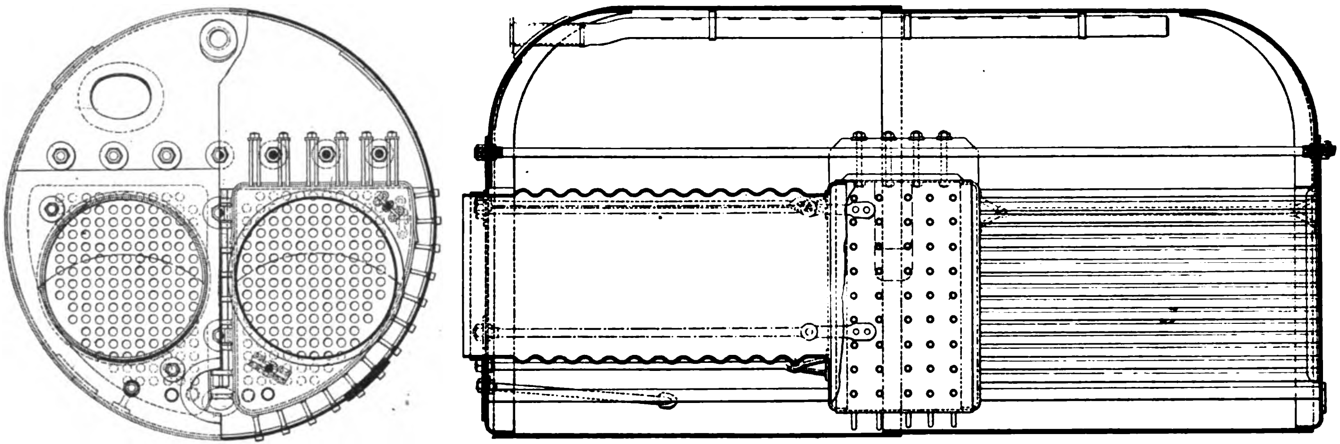


FIG. 2.—Gunboat Type, Direct Fire-Tube Boiler.

The Direct Fire-Tube Boiler—Gunboat Type.—Fig. 2 shows two views of the gunboat type of boiler fitted in ships of light draft and little vertical height of boiler space, so that the top of the boiler may be brought below the water-line. They are fitted on the gunboats of the *Yorktown* class and others. In order to be able to get at the back ends of the tubes, for cleaning and overhauling, extra lengths of fire-room must be allowed there. In order to put in the tubes without increasing this space too much, the athwartship bulkhead between the forward and after boiler compartments has removable sections opposite the tubes. By this means, as the boilers on the same fore and aft line are placed back to back, the space back of both boilers can be utilized for either boiler. The connections and uptakes, not shown, are at the back of the boiler. As the top of the furnace is very near the water level (it is, as shown, on a level with the top row of tubes), this boiler evaporates very quickly and more efficiently than the return-tube type. The total heating surface for the space occupied is small.

The boilers of the *Yorktown* have three furnaces with a common combustion chamber; those of the *Petrel* have two furnaces with a common combustion chamber.

The principal component parts of fire-tube boilers and the methods of securing them together are as follows:

The **shell plates** are of class B boiler-plate steel.* The circumferential seams, where secured to boiler heads, are double riveted. The circumferential seams of the middle-shell plate are treble riveted, as may be seen by an inspection of Plate I. The longitudinal seams are double butt strapped and treble riveted, as shown in Fig. 4. The right-hand figure represents a section on *X′Y′*, Fig. 2, Plate I, the section passing through the two rivets shown full in Fig. 4.

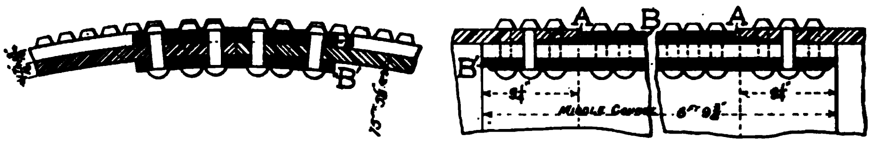


FIG. 4.—Double Butt Strap Longitudinal Seam.

The inner butt strap *B′* is rectangular, like the rest of the butt straps, and needs no special fitting at the ends. The outer butt strap *B* is planed down on each side to form a lip which passes under the outer courses. The latter are chipped and filed, or planed before bending, on the inside to suit the lips of the butt and make smooth joints. Enough clearance is left at *A, A* for calking.

Fig. 4a represents a section on *X″Y″*, Fig. 2, Plate I. The outer

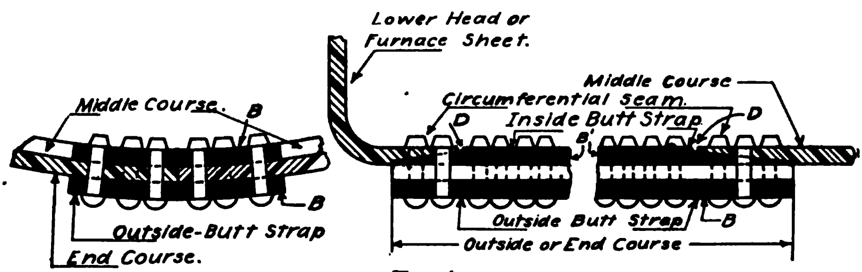


FIG. 4A.

strap, *B,* is rectangular, except for the removed corners at the ends. The inner strap, *B′*, is planed down at the ends to fit properly shaped recesses in the middle course edge and the furnace sheet flange, as shown. Sufficient clearance is left at *D* for calking.

* Class B boiler-plate steel is specified to have: (a) A tensile strength of 58,000 to 65,000 pounds per square inch; (b) an elastic limit of one-half (a); (c) an elongation of 25 per cent in a length of 8 inches; and (d) a maximum limit of .035 per cent of phosphorus and sulphur.

Hydraulic riveting is required wherever it can be used; where the riveting must be done by hand, the holes must be coned and conical rivets used. All of the joints in the shell can be made by machine-riveting, and the holes are, therefore, drilled as shown on the left in Fig. 5; those for hand riveting are shown on the right.

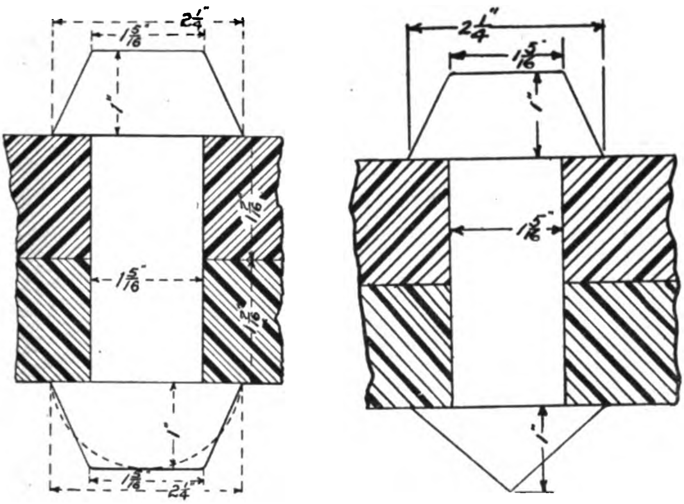


FIG. 5.—Methods of Riveting.

All holes are drilled $\frac{1}{16}''$ larger than the rivet. With machine-riveting, the end of the rivet is formed either into a button point (dotted lines), or into a truncated cone. With hand-riveting, the conical point is generally formed.

Head Sheets.—The furnace manhole, handhole and stay rod openings of the lower head sheet or furnace plate are shown in Fig. 6.

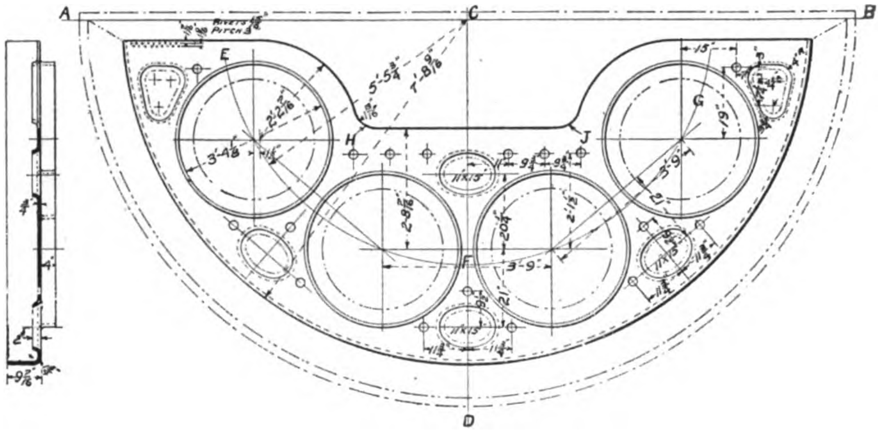


FIG. 6.—Lower Head or Furnace Sheet.

The middle head sheet or front tube sheet is shown in Fig. 7.

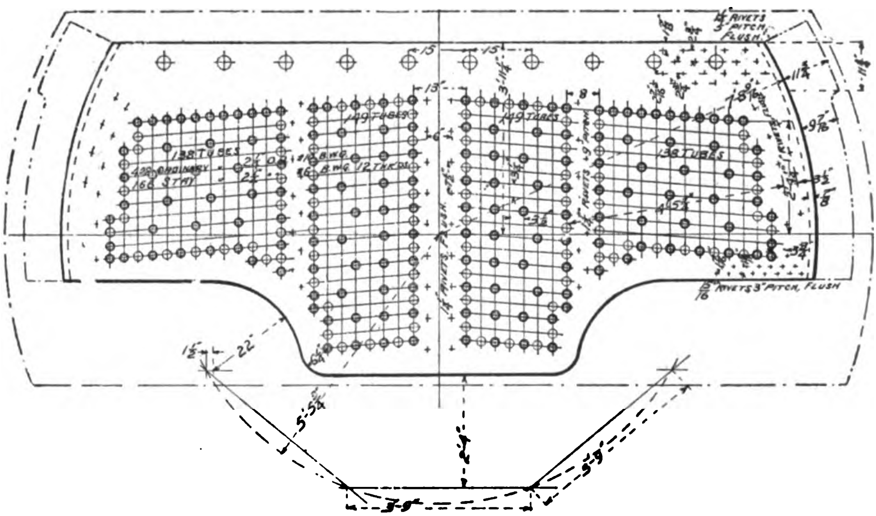


FIG. 7.—Tube Sheet.

The shape of the top head sheet may be seen from an inspection of Fig. 1, p. 18. It has stay openings, manhole and boiler fitting openings as necessary.

In both the figures, the outer broken line shows the original size of the plate from which the finished sheet was made, and the inner broken line shows the developed surface of the finished sheet.

The methods of flanging the head sheets and connecting them to the shell plates are shown in Fig. 8. The head sheets are made with

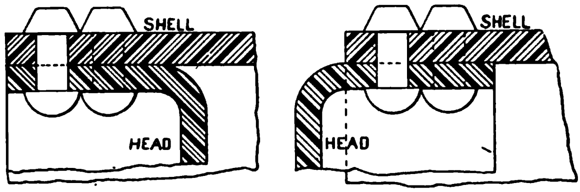


FIG. 8.—Flanging Heads to Shell.

the flanges turned inward, as on the right, or outward, as on the left. The method shown on the right is the general practice.

Fig. 9 shows the method of flanging and riveting the head sheets together.

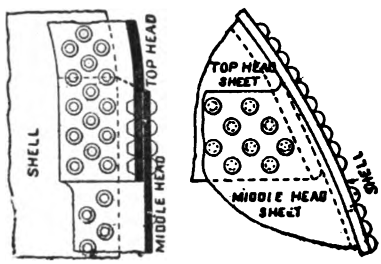


FIG. 9.—Riveting Head Sheets.

Fig. 10, on the left, shows the method of securing the combustion-

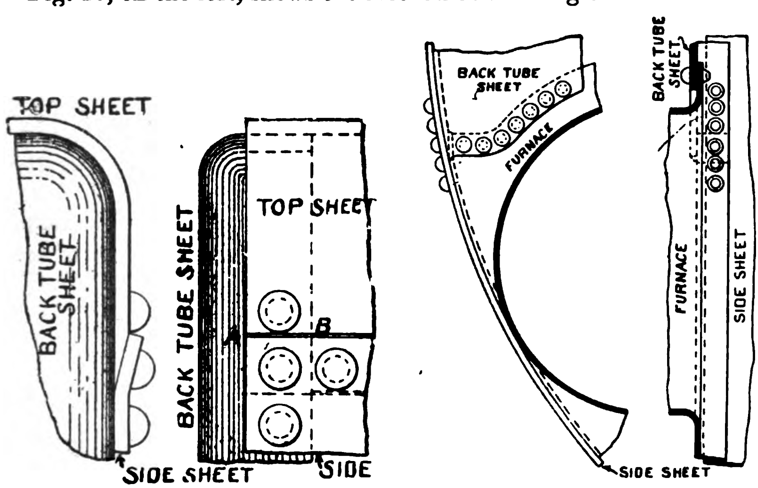


FIG. 10.—Riveting Combustion-Chamber Sheets.

chamber sheets together; and, on the right, the method of securing the combustion-chamber sheets to inner end of the furnace.

Fig. 11 shows the method of bracing the flat top of combustion chamber by means of girders.

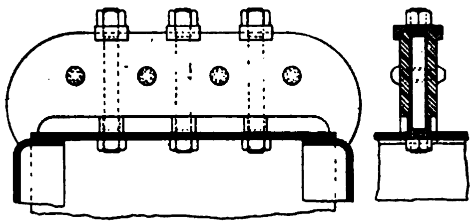


FIG. 11.—Girders for Bracing Top of Flat Combustion Chamber.

Fig. 12 shows the same by means of angle-bar girders with curved top plates; also the method of bracing the flat back sheet of combustion chamber to the back head sheet of single-ended return fire-tube

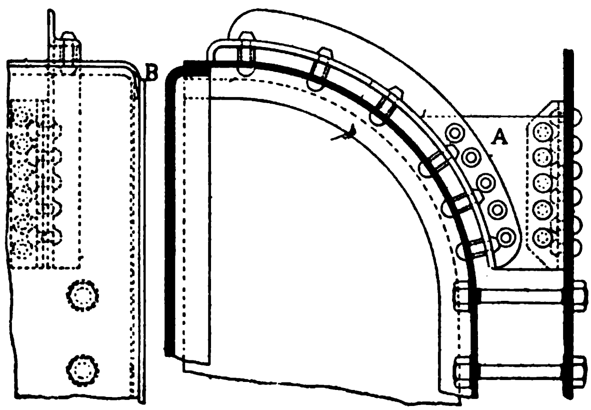


FIG. 12.—Girders for Bracing Top of Curved Combustion-Chamber Sheet.

boilers, or of tying together the two back combustion-chamber sheets, in double-ended return fire-tube boilers, by means of screw stays.

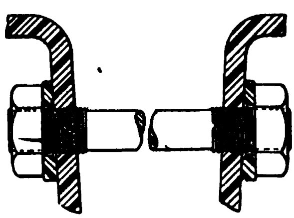


FIG. 13.—Screw Stay Bolt.

Fig. 13 shows the screwed stay bolt bracing the back combustion-chamber sheet; the same method is used to brace the flat side combustion-chamber plate to the shell of the boiler.

Fig. 14 shows the method of fitting through stays at the head sheets. The upper sketch shows the method of fitting washers where the stay passes through the sheet at right angles to it; the lower one shows the method where the stay goes through the sheet

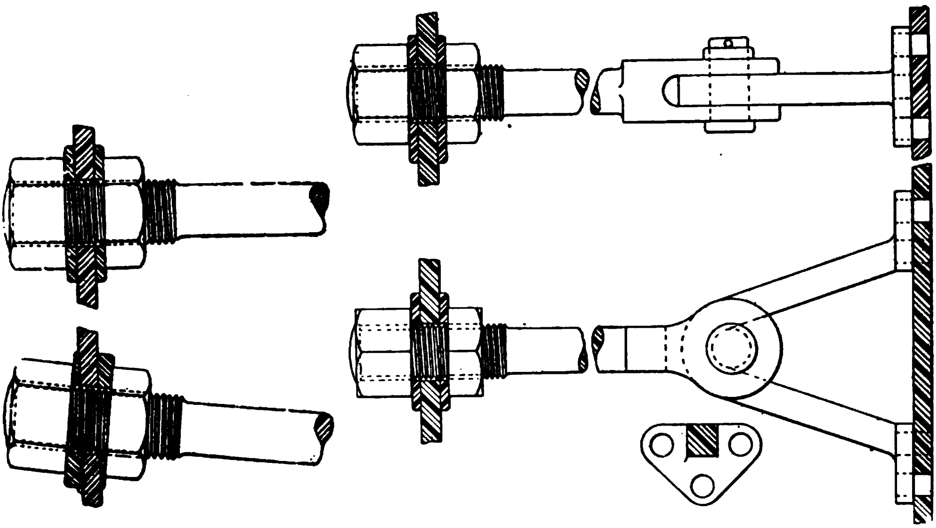


FIG. 14. FIG. 15.

Braces and Stays.

at an angle other than a right angle. Fig. 15 shows the method of connecting the stays to front combustion-chamber sheet.

Furnace.—Although the cylindrical furnace is less efficient than the rectangular one, chiefly on account of the limited space above and below the grate, yet it is the only one used in fire-tube boilers. It is easier to manufacture; it can be and is made with only two joints which need be kept tight, one at each end; and, as it requires no stays, the interior of the boiler, around the furnaces, is accessible for cleaning. These advantages outweigh its one disadvantage.

The older form consists of two or three short plain cylinders, riveted to each other by flanges turned on the ends, with a stiffening

ring between the flanges. This joint is called an *Adamson ring* and is shown at *A* in Fig. 16. For pressures, say, above 80 pounds, the plain furnace would not be strong enough without making the plates too thick. The necessity for increased strength led to the adoption of the Fox corrugated furnace, made in one length, as shown at *B*. Later forms of this type are shown by the Purves ribbed flue *D*, and the more recent Morison suspension furnace *C*, which is a combination of the Fox and Purves.

The Fox furnace *B* is of equal thickness throughout, and has narrow corrugations, spaced about 6″ between crests or tops, and

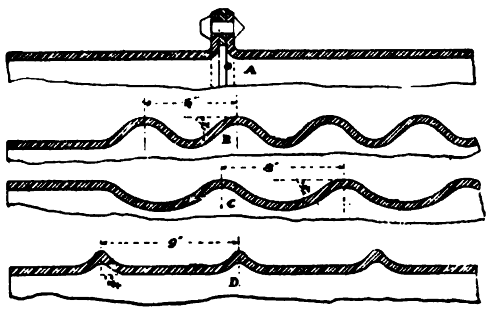


FIG. 16.—Furnaces.

projecting equally above and below the mean diameter of the furnace. The narrow cavity formed on the water side by the inward groove, 1½″ deep, gives good opportunity for an accumulation of deposits, which is rather difficult to remove properly. As these cavities are nearer the fire, the material, if not clean on the water side, becomes unduly heated and frequently cracks at the bend. This defect is overcome in the Purves furnace *D*, which has the strengthening ribs in the water space, and, therefore, offers no cavities. But the flat surfaces, 9″ between the ribs, being the weaker, are the first to sag or collapse. Owing to the stiffening rib, the thickness of the furnace, and, therefore, its strength, is not the same throughout. In the Morison furnace *C* the corrugated form is retained for strength, but, by making the outward corrugations shorter and utilizing them as stiffeners, the inward corrugation, *suspended* between them, can be made longer, 8″, the small cavities being thus avoided. The thickness of the furnace is uniform.

All furnaces are made of steel, the plate being usually $\frac{9}{16}$″ thick, with slight variations depending on the quality of the material and the boiler pressure. The least internal diameter varies from about

36" to 42". The corrugations of adjacent furnaces are made to alternate.

Fig. 17 shows a finished suspension furnace with small flanges, as fitted for separate combustion chambers. This furnace is a removable one, the diameter of the straight part at the back being less than that of the corrugations. The diameter of the straight part at the front end is made slightly larger than that of the corrugations, to facilitate the entry of the flue into the furnace hole in the lower sheet of the boiler.

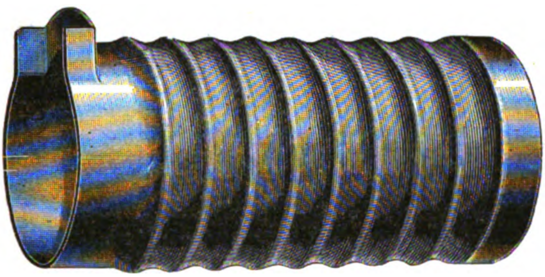


FIG. 17.—Suspension Furnace.

Tubes.—These are always straight and are of two kinds, ***ordinary*** and ***stay tubes,*** the latter being the heavier or thicker, but both having the same external diameter. The material of tubes is seamless cold-drawn steel.

Ordinary Tubes.—These, which are the more numerous in a boiler, are now made from No. 9 to 12 B. W. G. (.148" to .109") thick, with the front ends swelled to a slightly larger external diameter, from $\frac{1}{16}$" to $\frac{1}{8}$", to facilitate their entry and removal. The holes in the tube sheets are drilled slightly larger than the tubes, so that the latter can be pushed into place by very slight pressure, and the tube holes are rounded at edges to prevent cutting the tubes when being expanded. Both ends of the tubes are then made tight by an *expander.** The back or combustion-chamber end of the tube is then *beaded* over, as shown, to protect the end from the fire and to add a little to the holding power.

Stay Tubes.—These, as their name shows, act as stays between the two tube sheets, and are, therefore, secured in a different manner. They are usually No. 6 B. W. G. (.203") thick, and are re-

* The details of the expander and the method of its use are explained in the chapter on "Accessories."

inforced at both ends to an external diameter usually $\frac{1}{8}''$ greater than the rest of the tube, the bore of the tube remaining uniform from end to end. The front ends are then swelled an additional $\frac{1}{8}''$, so that the external diameter at this end is $\frac{1}{4}''$ greater than the body of the tube. Both ends are then threaded, usually parallel, but sometimes tapered at the front end. The tube is screwed into the threaded holes in the tube sheets until a tight joint is made in the front sheet. The back end is then expanded and beaded over, and this end and the adjacent sheets are further protected by a cast-iron *ferrule,* as shown. These ferrules, which are sometimes also used in the back ends of the ordinary tubes, have an internal diameter of from $1\frac{1}{2}''$ to $1\frac{3}{4}''$, and are simply driven into place by slight

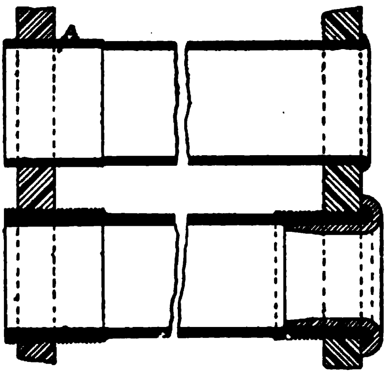


FIG. 18.—Ordinary and Stay Tubes.

hammering. The round cap projects over the beaded tube end and, by conducting the heat to a part of the tube surrounded by water, protects the tube end and joint from the direct action of the hot gases. When the caps are burned off, the ferrules can be renewed easily. When cleaning tubes with brushes, these ferrules are liable to be pushed out. Ordinary tubes, when much reduced in thickness by frequent expanding, may be strengthened for a time by straight ferrules expanded in the ends.

The holes in the tube sheets are drilled in vertical and horizontal rows, the spacing between vertical rows being the greater.

This arrangement gives better opportunity for cleaning the tubes on the water side and improves the circulation. While more tubes could be put into a given tube sheet by *staggering* them, *i. e.,* putting them in zigzag, this arrangement interferes entirely with the cleaning and does not improve the circulation.

two sets of flame plates and baffle plate *JJ* and *II* is the ***second pass,*** and that between the flame plates near the front and the front headers is the ***third pass.*** Thus, the gases pass up through the first, down through the second and up again and out through the third pass.

This boiler is fitted for burning coal; for burning coal and liquid fuel, either singly or in conjunction; and lends itself very readily to being fitted for burning liquid fuel, on account of its high combustion space and large furnace volume, as shown in Plate IIIb. When the boilers are fitted to burn either coal or oil or both, the oil burners are placed between the furnace doors. When burning oil only, the grate bars are removed and the ash pan is covered with bricks or with cinders and ashes.

Fig. 25 shows the Babcock and Wilcox boiler complete, showing the cleaning and dusting doors on the sides and the system of lagging the casing of the boiler with non-conducting material. The cleaning doors have smaller doors in them, for inspection as to the

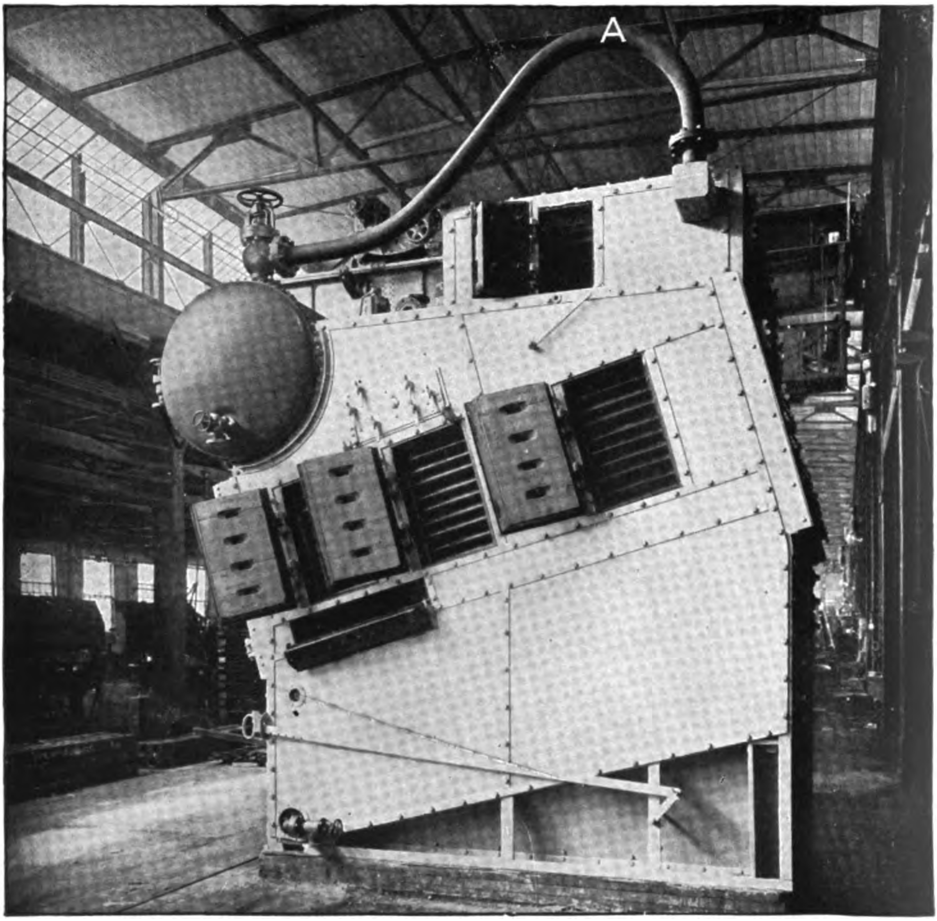


FIG. 25.—Babcock and Wilcox Boiler.

condition of the combustion in the different passes and as to cleanliness of the outside of the tubes. Steam or compressed-air nozzles are entered through the smaller doors for tube-cleaning when under way. Bottom blow connections are fitted at the side of the bottom of each front corner upright; the other fittings are secured to pads on the drum or drum heads.

Steam Drum Heads.—Fig. 26 shows the form of the heads for the steam drums. They are made of one piece with manholes and openings for other boiler fittings, and are bumped into shape.

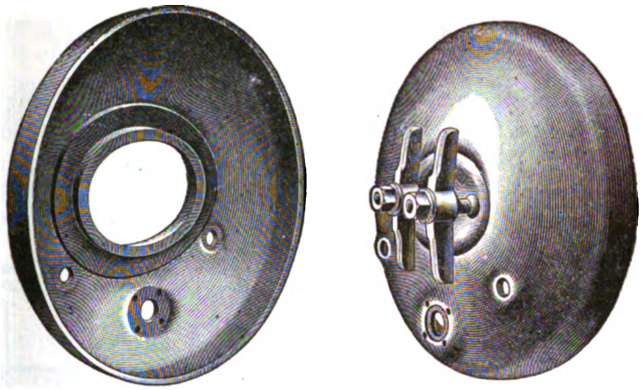


FIG. 26.—Head of Steam Drum.

Superheater.—The superheater when fitted, is as shown in Fig. 27. It consists of two steel boxes, *A* and *B,* lying across and on top

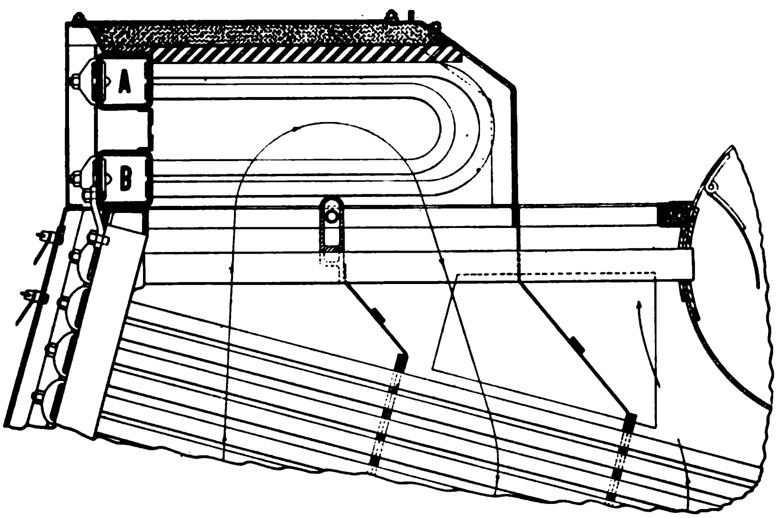


FIG. 27.—Superheater.

of the boiler at the back; these boxes are connected to each other by a series of pairs of 2″ steel tubes.

The upper box *A* is longer, as the pipes for the entering and the superheated steam are connected to its ends. The tubes extend forward from the boxes about two-thirds of the distance between the steam drum and the boxes; the rear casing of the uptake comes down at the bend of the tubes. The boxes are secured to the rear headers and to each other by channel irons and braces.

The interior of the upper box is divided into three lengths by two diaphragms, and the lower one into two lengths by one diaphragm. The steam from the boilers, which enters at one end of the upper box, is thus forced to travel down and up and through

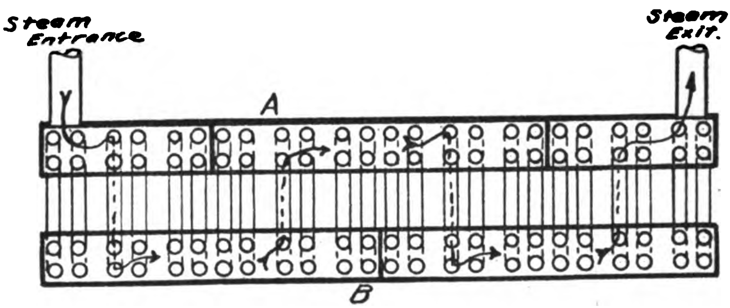


FIG. 28.—Superheater, Back View.

the tubes four times before it leaves the upper box at the other end, thus taking up the heat of the gases of combustion to the best advantage. Fig. 28 shows the subdivision of *A* and *B* and course of steam through superheater.

The baffles plates among the generating tubes are fitted differently from the usual arrangement, owing to the presence of the superheater. There are two baffles, as usual, but the rear one extends from the lower tubes of the superheater down to the top of the

4" tubes over the fire. The front baffle extends down from the rear casing of the uptake only part way. The gases enter among the generating tubes at the back of the furnace, rise into the superheater, thence down between the two baffles, and up into the uptake near the front of the boiler, as shown by the arrows.

The boxes are fitted with handhole plates giving access to four tubes, as in the headers. The tubes are expanded into the boxes and are flared after expanding. Dusting doors are fitted in the sides of the superheater casing. The heating surface of each superheater is about 10% of that of the boiler.

Details of Construction.

As the construction of this boiler is very simple, not much need be said in explanation of it.

The Drum.—This is made of steel; the shell is made of two plates, with double butt straps. One of these plates extends around one-fourth, and the other three-fourths, of the circumference, the smaller plate being in the lower back quadrant of the shell. The holes for the return tubes and for the connecting tubes to the front headers are drilled in the center-line of the butt straps. The tubes are expanded into the straps only, the holes in the shell plates being slightly larger. The drum is built under the same general specifications as are fire-tube boilers. The heads are formed in single heat, by hydraulic presses, to a spherical surface, the radius of which is equal to the diameter of the shell.

The manhole is flanged in the shell plate or head, with a stiffening ring of sufficient thickness to form, with the edge of the plate, a seat 1" wide for the gasket. Fig. 26 shows a drum head with manhole. The plates for the latter are of compressed steel 11" by 15", faced to fit the oval hole.

Headers.—The corrugated headers are formed into seamless-drawn tubes from square blanks of open-hearth sheet steel, $\frac{1}{2}$" thick. In a single heat, they are squared on a mandrel and corrugated on both sides by hydraulic presses; and, after annealing, they pass to multiple tools that bore and face the handholes, other multiple drills being used for boring the tube holes. By the use of this form of header or manifold for connecting the tube ends, a perfectly flat tube sheet is obtained, which requires no stays or braces, as the sides of the header are sufficient for that purpose for

any steam pressure required. In the latest design of rear header, that portion of the extension which forms the tube sheet for the return tube is pressed out or pocketed, so that the tube seat will be at right angles to the axis of the tube. The ends of the headers are closed by $\frac{3}{4}''$ steel plates welded into place.

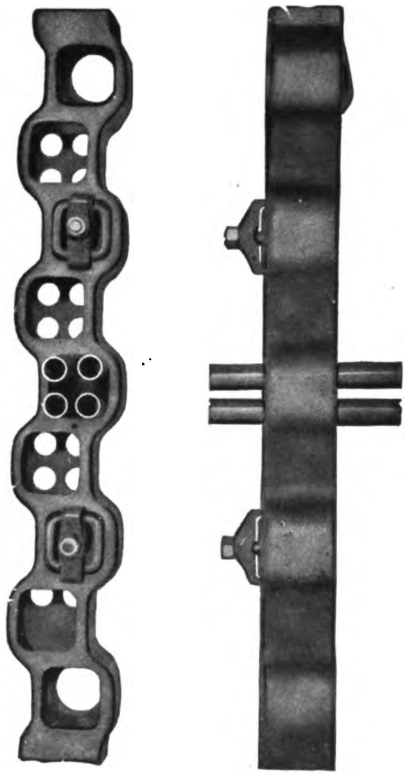


FIG. 29.—Headers.

The header is shown in Fig. 29. The tubes are arranged in clusters of four, each cluster being opposite a handhole 5" square. It will be seen that the tubes may be examined, cleaned, or renewed without difficulty.

Overhauling the Boiler.—The tubes can be cleaned on the inside by straight brushes or, if necessary, by scrapers, or by steam or air turbines. The baffle over the furnace is likely to warp and need renewal after some time.

Spare Parts and Tools.—The tubes being straight and of commercial size, only the usual allowance need be carried. A few side boxes, handhole plates, dogs and gaskets complete the allowance of special parts necessary. Short and long nipples may be cut from the 4″ tubes and annealed.

Ordinary tube expanders of the proper sizes, and an expander fitted to work from the farther end of the short connecting tubes, some metal tube plugs, and an extractor should be on board.

Renewing Defective Tubes.—A defective tube can be replaced by a new one as quickly as it can be plugged, and no more water is lost by the former process than by the latter. A good boilermaker, or machinist, can replace a tube in a very short space of time.

Cleaning.—The main objection to boilers of this type, of which there are many in the United States Navy, is the expense in labor, time and material that is required to thoroughly clean them when cleaning becomes necessary. A new gasket for each handhole plate removed is generally required. Each handhole plate must be cleaned, and also the gasket seat in the header; and, after cleaning, each handhole plate must be made tight.

Renewing Flame Plates.—The flame plates of the baffles among the generating tubes may work loose and fall down, on account of vibration of the boiler or bulging of the tubes. When the flame plates fall down, some of the gases of combustion take a shorter path to the uptake and there results a marked falling off in the efficiency of the boiler. The plates are renewed by laying them flat and passing them between the tubes until in the required position and then turning them upright on edge. They are grooved on each side to fit between the rows of tubes, and the grooves are chamfered on the opposite edges so that they may be more readily turned from the flat to the upright position.

Securing Brick Linings to Furnaces.—In the oil-burning boiler, the brick lining of the furnace must be firmly secured to prevent its jarring loose on account of vibration. There are several methods in use. Fig. 30 shows the method employed for the boiler in Plate IIIb.

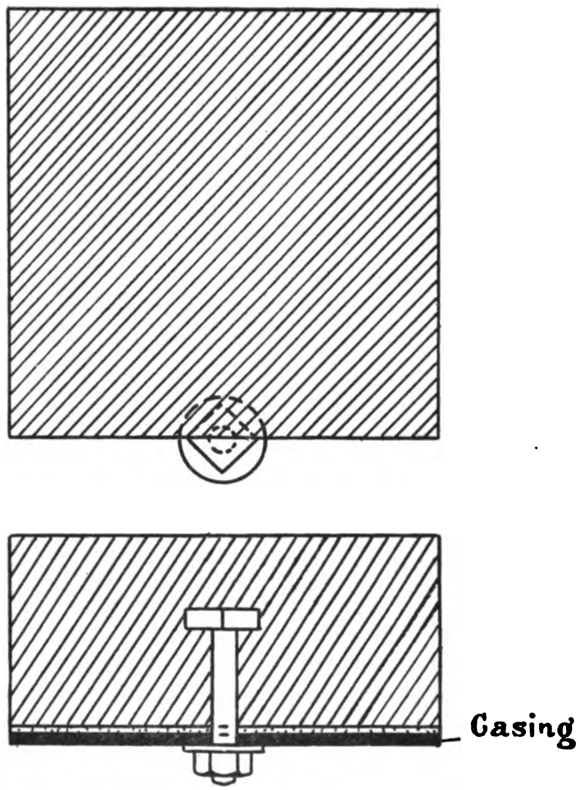


FIG. 30.—Method of Securing Fire Brick.

The Dyson Boiler.

The Dyson Boiler, designed by Rear Admiral C. W. Dyson. U. S. Navy, consists essentially of the cylindrical steam drum *A,* two water drums *BB,* tubes *C,* and superheater *D, E,* and *F,* Plate V.

The *water circulation* in this boiler is as follows: The feed water is forced into the steam drum *A,* and flows down to the water drums *BB,* through the tubes furtherest away from the fire: the

steam and water flow up to the steam drum through the hottest tubes. Steam then flows from A, through drypipe, stop valve, and steam pipe, to D, up through tubes E to F, then out through drypipe to steam line.

Furnace Gas Circulation.—The relative position of the superheater tubes in the lanes among the generating tubes provide baffling in wake of the uptake. This causes the gases in the lower part of the furnace to back completely through the lower half of the generating tubes instead of having a tendency to short circuit directly from the furnace up towards the uptake, leaving a dead pocket at the lower half of the generating tubes.

The special advantages claimed for this boiler are:

1. The ability to revolve the lower superheater drum in its saddle, thus bringing the superheater tubes out into the open for examination and renewal.

2. The lanes provided among the generating tubes in which the superheater tubes are located make it possible to give a more thorough examination to the outer half of the generating tubes of the boiler than was possible with the ordinary tube spacing, and also render it possible to renew tubes in the outer half of the nest with less sacrifice of good tubes to reach the faulty ones.

3. The relative position of the superheater tubes in the lanes among the generating tubes provide the major baffling in the wake of the uptake, thus causing the gases in the lower half of the furnace to back completely through the lower half of the generating tubes instead of having a tendency to short circuit directly from the furnace up towards the uptake, leaving a dead pocket at the lower half of the generating tubes.

4. By the arrangement of drums and lanes, the ability to increase and decrease superheating surface in comparison with generating surface becomes almost unlimited up to the 50-50 point. Also the large superheating surface gives a large area for the flow of steam through the superheater and reduces the drop through the superheater to the lowest possible amount, a certain amount of drop being necessary in order to insure flow of steam through all the superheater tubes. This is provided for by drypipe shown inside the superheater drums, which causes practically an even draft of steam to be taken from all parts of the lengths of these drums. While not shown in the drawing, at the upper ends of the three outer rows of superheater tubes ferrules are inserted decreasing the area of these

tubes at the upper ends and thus forcing more steam through the inner rows of tubes where the gases are of higher temperature.

5. By inserting tubes in the lanes as shown, these lanes can be made of any depth desired, and the tubes extended into any temperature which may be desired.

6. By having the superheaters so located as to roll out to the side, the length of firerooms may be brought down to a minimum instead of being limited by the space necessary to draw superheaters out from the front of the boiler into the fireroom.

7. All steam connections can be made at one end of the drums and means can be provided for cutting out either or both superheaters and for using either saturated, mixed or superheated steam, as may be desired.

The steam connections are shown in the small plan.

The Normand Boiler.

The **Normand oil-burning boiler** shown in Plate VI is installed on a number of destroyers. There are three cylindrical drums. The upper one shown in the plate is the steam drum *A;* the two lower ones are the water drums *B.* The steam drum is connected to each water drum by curved generating tubes *C,* and by a downcomer *D,* to each water drum at the back of the boiler. The front of the steam drum is tied to the front end of each water drum by a hollow stay *E;* in addition to supporting the steam drum this stay acts as a small downcomer.

Each boiler has one furnace fitted with oil burners. The boiler front carries an air casing *F,* through which air is admitted to the air cones *G,* and through them into the furnace around each burner nozzle. Each burner has its individual air cone.

The furnace gas baffling is arranged as follows: The inner rows of tubes, C' (sectional plan), are bent back into the spaces between the second rows, C'' (section at *EF*), making a baffle wall from the boiler front for a distance of about three-fourths of the length of the furnace. The tubes at the back of the boiler are spaced more openly from the end of the wall to the back of the furnace than the other boiler tubes. The two outside rows of tubes, C''', are fitted in the same way for the whole length of the tube plates, and form a baffle wall between the tubes and the boiler casing. A vertical

plate *H* (longitudinal section) extends from the steam drum for a distance down through the tubes; the lower edge of this plate is shown (on section at *EF*) at *H'*.

The **circulation of the gases** is shown on the sectional plan and on the longitudinal section by arrows, and is as follows: The gases flow to the back of the furnace, around the end of the tube wall, then towards the front, through the tubes, between the two 2-tube walls, and under the plate *H*. They thence escape to the uptake through the space *I* at the front of the boiler.

The steam drum is made in two halves joined by treble riveted lap joints on each side. There is a manhole at the back, on top of the shell, and one in the front head. There is a handhole in the back head. The plate shows the method of lining the furnace; it also shows the air cones for the burners.

The **water circulation** is from the steam drum *A*, through the rear downcomers *D*, and the stay rods *E*, to the water drums *B*; the steam and water rise through the circulating tubes *C*, and enter the steam drum in the water space. A short drypipe is fitted in steam dome.

The construction of the boiler itself is very similar to the coal-burning Normand boiler, shown in Fig. 36.

This boiler is fitted on the torpedo boats of the *Craven*, *Bagley* and *Blakely* classes, and, in a slightly changed form, on the *Gwin* class and on the *Morris*. It is also fitted on the scout cruiser *Chester*. It has small curved tubes which discharge below the water level. Fig. 36 shows a front elevation, half in section, of this boiler, as fitted on the *Bagley* class. The generating tubes are curved for the greatest part of their length, and enter the drums normally. The tubes forming the sides of the furnace do not meet in the middle at the top; this small space is filled in with fire brick to protect the steam drum from the gases, and to close the small spaces left between the upper ends of the two inner rows of tubes. The front and back of the furnace are built of brick.

Each side of the furnace, for about two-thirds of its length from the front, is formed of a wall of tubes; in the remaining one-third, the tubes are open and permit the gases to pass between them. The sides of the grate are brick walls, which not only protect the lower drums and lower ends of the tubes, but also close the small spaces at the bottom of the tube wall. The two outer rows of tubes in each nest are bent to form a wall, which is complete, except at the upper part for about one-third the length from the front. The

rest of the generating tubes are staggered. By this arrangement, the products of combustion are forced to enter between the open-spaced tubes at the back. They then *return* between the tubes and rise, through the open spaces left in the outer wall, into the uptake at the front end of the boiler.

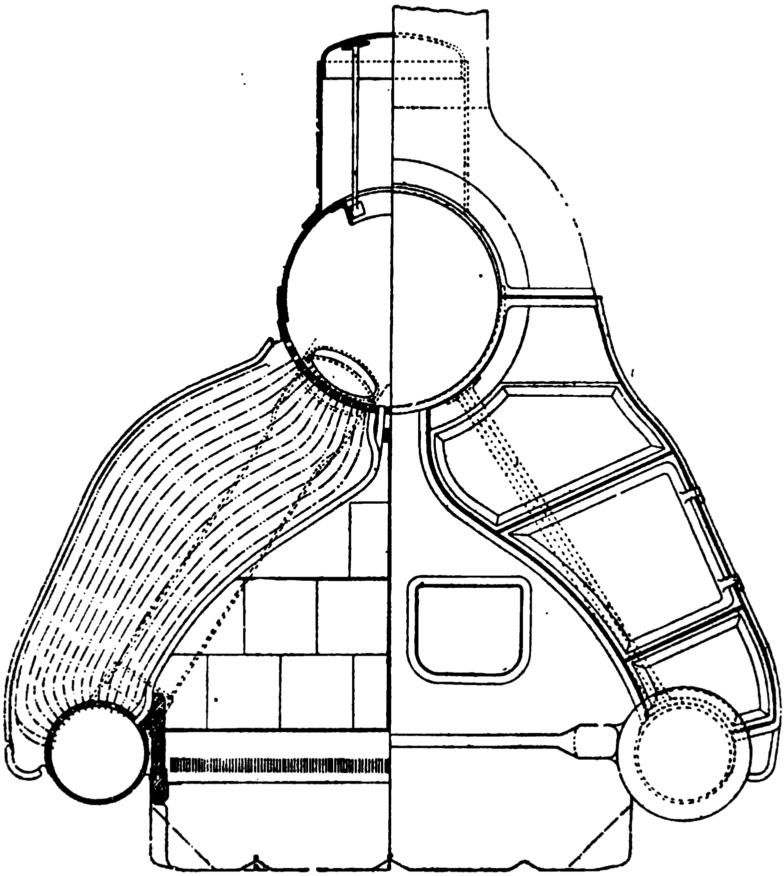


FIG. 36.—Normand Boiler (Express Type, Coal-Burning).

In the twelve boilers for the *Chester,* which are like Fig. 36, the steam and water drums are 40″ and 18″ in diameter, respectively, and have welded joints on the shell. The grates are 7′ 2½″ long, and the tubes 1⅛″ in outside diameter, and .134 thick. The down-comers in this case are at the front of the boiler and the uptakes are at the back. This causes the tube walls next to the furnace to

be open at the front of the boiler, which just reverses the circulation of the gases of combustion, as given above, for the *Bagley* class.

The Thornycroft Boiler.

A **Thornycroft** boiler, fitted for burning liquid fuel alone, is shown on Plate VII. This plate shows the method of securing the fire brick lining the furnace, the front casing fitted for admitting air to the burners, the burner openings and the method of baffling for gas-circulation.

This boiler is fitted in the *Ammen, Burrows, McCall, Monaghan, Roe* and *Terry*.

As may be seen from the plate, it has one steam drum and two water drums; the tubes, of seamless-drawn steel, all enter the steam drum in the water space. There is one large downcomer tube from the front end of the steam drum to each water drum; the steam drum projects through the front casing and the downcomers are outside of the casing. There are no baffles or passes to cause the gases of combustion to circulate in any particular way through the tubes; the flow of the gases is direct. A deflecting plate *A* is placed in the uptake space and prevents the gases from passing from the top of the furnace direct to the uptake. The gases pass through a reduced opening between this plate and the casing. This keeps the hot gases of combustion in contact with the heating surfaces of the boiler for a longer period of time and prevents high smoke-pipe gas temperatures. The boiler casing is constructed of galvanized steel plates and angles, lagged on the inside with asbestos and magnesia. In the wake of the tubes this casing is made in sections to allow for examination and repairs. At the back of the boiler there is a 2″ air space between the non-conducting lining and the plates. The front casing, between the downcomer tubes and the bottom of the ash pans, has an air space 15″ in depth, and it is fitted with light air-regulating doors admitting air from the fire-room into the casing. The amount of the opening of the doors can be regulated; in case of a large steam leak in the furnace, they close automatically. The furnace is lined at the front and back, and at the sides, up to the water drums, with fire-brick tile 2½″ thick and 9″ square. The bottom of the furnace is lined with fire brick 1½″ thick by 9″ square, laid in two thicknesses so as to break joints. Sight holes are placed so as to permit observation of the products of combustion. The downcomers and all tubes are expanded into the drums.

There are at present four types of Thornycroft boilers in the navy, of which the one in Plate VII is the latest. It is a radical change in design from the first three, which vary among themselves only in arrangement of drums and tubes. The Thornycroft principle up to this last type has been to have all generating tubes enter the steam space of the steam drum. Many of the water-tube boilers with accelerated circulation were originally designed to have the upper end of the tubes enter the steam space, but practically all of them have changed to having the tubes enter the water space of the steam drum; in other words, the upper ends of the tubes are "drowned."

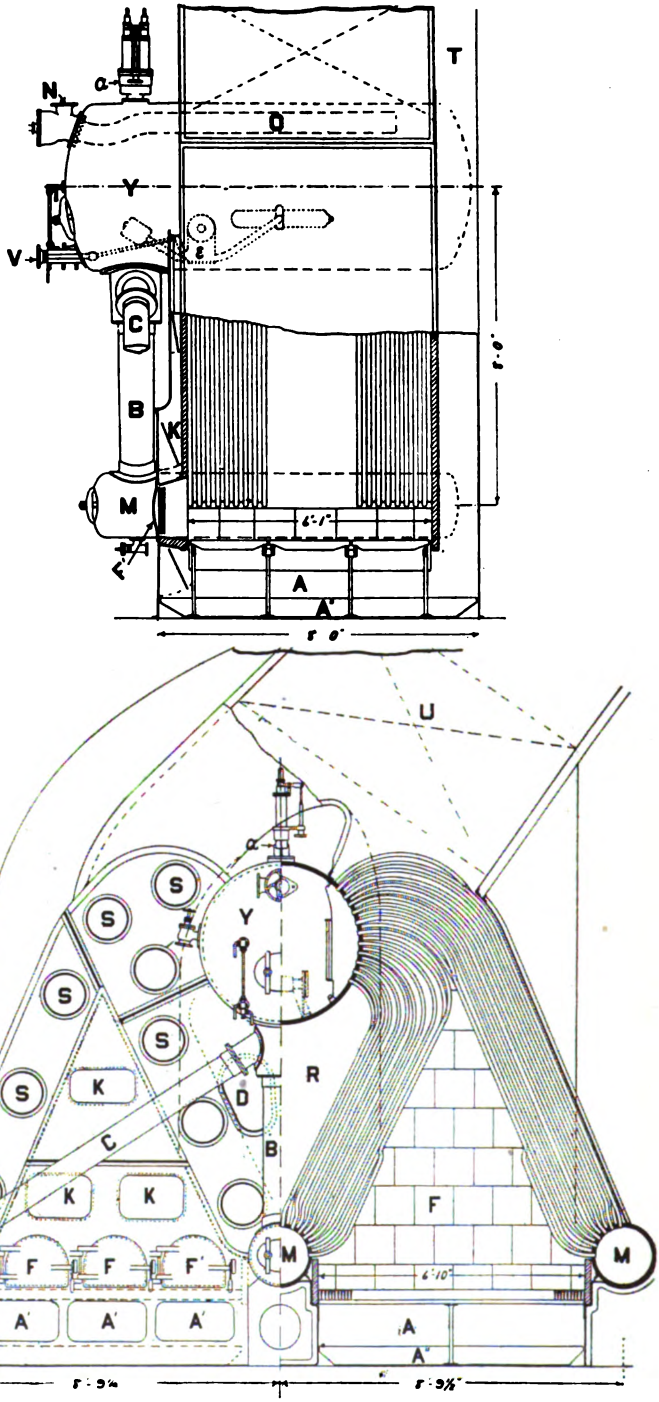


Fig. 39.—Thornycroft Boiler (*Ohio* Type).

Ohio Type.—The original Thornycroft principle is illustrated in the *Ohio* type of boiler, shown in Fig. 39. This type is a combination of the several types of coal-burning Thornycroft boilers. It is fitted on the *Ohio, Missouri* and *Ozark.*

The wing drums are of the same size as the central water drum, and are fitted with a large number of generating tubes. The down-comers *B* and *C, C* are outside the casing. There are two lofty furnaces, the sides and tops of which are formed by the wall in each nest of tubes. The gases of combustion from the furnace enter the openings at the bottom on each side, rise between the inner and outer walls of each nest, and pass through openings at the top into the uptake *U* directly above the tubes. The heart-shaped space *R* is, therefore, not used as a connection for the gases. The openings in the front of the casing, when the closed fire-room system of draft is used, are the same as before. They consist of non-return air doors *K, K* by which the supply of air above the grates can be regulated; sight doors *S, S* for the examination and sweeping of the tubes; and soot doors *D, D* for the cleaning of the heart-shaped space *R.* The generating tubes vary from 1¼″ to 1⅜″ in diameter, and, as in the previous types, discharge the water and steam into the drum *Y* above the water-line.

Although the Thornycroft boiler is extensively installed in the U. S. Navy, its complicated structure and the difficulty of cleaning and repairing it have, in recent years, prevented a continuance of its installation.

The Yarrow Boiler.

The **Yarrow boiler** for burning oil fuel, shown in Plate VIII, is a straight-tube boiler of the accelerated-circulation class. Several destroyers are fitted with boilers of this type. The coal-burning boilers of the Yarrow type are practically the same as the oil burners, the difference being in the details of the furnace front and furnace.

The Yarrow boiler is used extensively in the British Navy in both the large-tube and the small-tube types.

The boiler consists of a steam drum and two oval water drums; each water drum is connected to the steam drum on its own side by straight seamless-drawn steel tubes, expanded into each drum. The steam drum is made up of a top drum sheet and a tube sheet, butt-jointed with double butt straps. The joints are on a line parallel with the axis of the drum. The tube sheet is made much thicker in wake of the tubes.

The water drums are made up in the same manner, except that the drum sheet laps over the tube sheet and the joint is double-riveted.

Water Circulation.—The feed water enters the steam drum, and flows down to the water drums through the tubes furthest away from the fire; the steam and water flow up to the steam drum through the hottest tubes. Some types of the Yarrow boiler have downcomers outside the boiler casing. Without downcomers the water circulation varies under the different conditions of steaming, and different degrees of steadiness of the ship. Tubes which, under certain conditions, act as downcomers, change to generating tubes with the changed conditions. Although the circulation path of the water is slightly in doubt, it is certain that the circulation is satisfactory, as there are many boilers of this type in successful operation. In some of the early Yarrow boilers an inclined flame plate partially blanked off some of the outer tubes from direct impinge of the flame, in order to keep the outer tubes cooler and have them serve as downcomers.

The latest system is to discharge the feed water into both lower drums through an internal feed pipe extending nearly the entire length of the drum. The internal feed pipe discharges into a pocket formed by a steel plate curved around the internal feed pipe, closed at both ends and shaped to direct the water upward through the two outer rows of tubes. Where the water discharges into the upper drum, a short baffle is so fitted as to direct the water outward toward the surface of the steaming level. The circulation is increased, and the system has resulted in a more satisfactory performance of the boiler.

Furnace-Gas Circulation.—The gas-baffling system of the Yarrow boiler is very simple. An inclined flame plate *A* is secured at the upper end of the outboard row of tubes. The gases in the upper part of the furnace are deflected down by this plate and prevented from passing directly to the uptake. The opening to the uptake at *C* is reduced, in order to retard the flow of the gases and prevent high smoke-pipe temperature. In addition a flame plate *B* crosses the tubes at right angles about midway of their length. This plate retards the flow of gases somewhat and also causes a change in their direction on the way to the uptake.

Boiler Casing.—The casing is made up of galvanized steel plates, angles, brick-work, asbestos board and magnesia. The uptake casing has three sheets. Between the inner and middle sheets there is an

air space; between the middle and outer sheets there is non-conducting material. The furnace fronts and backs consist of galvanized steel plates, between which is placed asbestos board and magnesia; to the inner of these plates is secured a layer of 2″ brick-work secured as shown. The bottoms and sides of the furnace up to the water drums are covered with two thicknesses of 2″ brick, arranged to break joint. The front casing carries openings for the burners and their air cones in an enclosed compartment fitted with self-closing doors for regulating the air supply. There are doors in the casings in wake of the tubes for cleaning the tubes. There are observation windows just below the uptakes, and sight holes for observing the conditions of combustion.

Manholes, etc.—There are manholes in each steam and water drum; through these, leaky tubes can be plugged or expanded and cleaned. One of the advantages of the Yarrow boiler is its simplicity of construction. One of its disadvantages, and in fact one of the great disadvantages of most boilers with accelerated circulation, is that it is a very difficult matter to replace tubes without completely retubing one side. Tubes in the inner and outer rows, however, can be replaced easily.

The White-Forster Boiler.

The **White-Forster oil-burning boiler,** shown in Plate IX, consists of a large steam drum and two water drums, connected by relatively short tubes. In manufacture the tubes are curved in one plane only, and with the same radius of curvature; when placed in the boiler, however, a curvature both towards the furnace and toward one end of the boiler is obtained by slightly revolving the tubes before expanding them into place. This is plainly shown in Figs. 1 and 2, Plate IX.

The construction of the steam and water drums is similar to that described for the Yarrow boiler, except that the water drums are of circular cross-section and have the two sheets of the drum secured by means of double butt-strap joints, as shown. There is a manhole near the top of the front steam-drum head and one in the front head of each water drum. Large downcomer tubes at the back of the boiler connect the steam drum to each water drum.

The curvature and length of the generating tubes are such that a tube can be removed or replaced from the steam drum through the manhole.

They can be cleaned from the steam drum. The ends of the tubes can be expanded from the steam and water drums. Any tube can be withdrawn without disturbing the remaining tubes.

The **water circulation** is from the steam drum down the down-comer tubes to the water drums, and up the generating tubes to the water space of the steam drums as water and steam. No special water baffles are installed. The dry pipe, internal feed pipe and scum pan are the only internal fittings. This boiler, with its large steam drum, is noticeably free from priming, on account of the larger disengaging surface, which permits the steam bubbles to pass freely through the surface of the water without violent ebullition.

The **circulation of the furnace gases** is shown by the arrows in the plate. Baffle plates are fitted as shown at *A*, and *B*. The opening at the bottom of the uptake is reduced in area to retard the flow of the gases and prevent high smoke-pipe temperatures.

Some of the good points of this boiler are: (1) Its simplicity of design and construction. (2) Any tube can be replaced with ease. (3) The curvature of the tubes allows for expansion. (4) It is easy to clean, inspect and repair.

The coal-burning White-Forster boiler differs from the oil-burning boiler only in the details of the furnace front and furnace.

The White-Forster boiler is installed in the *Warrington, Mayrant, Patterson* and *Beale.*

The Ward Boiler.

Nearly all of our launches are fitted with this type, which was the standard boiler for steamboats. These boilers are either cylindrical or square in shape, the arrangement of tubes and other parts being shown in Fig. 43, which is a cut of a cylindrical boiler.

Round Type.—A circular manifold *A*, of cast steel, with a hollow projection for the furnace door opening, forms the base of the boiler and supports the grate. This manifold rests on a cylindrical ash-pit structure which is secured to the keelson. On the upper surface of the manifold there is a row of holes, into which vertical tubes of 1¼" inside diameter are secured by tapered screw couplings. These tubes are straight except at the top, where, by an easy curve, they are bent through 90°, and enter the vertical drum *D*, to which they are secured by tapered screw couplings. The upper part of the drum is of plate steel and cylindrical, and the lower part of cast steel, cylindrical where the bent tubes enter it and conical below that. As the diameter of the manifold is about 2½ times that of the drum, the tubes of each row from the manifold cannot enter the drum in the same horizontal plane. Half the tubes enter the drum in one horizontal plane and the other half enter in a slightly higher plane.

Into the conical bottom of the drum, a number of straight Field tubes *T*, of wrought iron or steel, usually 1½" internal diameter, are screwed. These tubes project into the cylindrical space inside of the vertical tubes and above the fire. The outer or lower end of each hanging tube is closed by a screw cap, and its inner end by a tight-fitting plug, in which are two small holes. Into each hole is fitted a small brass tube, open at both ends, one tube extending inside of the hanging tube to within an inch of the bottom, and the other and shorter one projecting about 4" into the drum. This is shown in the section of the outer hanging tube.

Around the inside of the drum, an inclined diaphragm *P* is fitted below the openings of the lower row of vertical tubes. This diaphragm separates the main generating tubes from the downcomers. By means of the internal feed pipe not shown, the feed water is delivered to the lower row of tubes, going thence to the manifold and returning to the drum by the tubes that enter highest. From the drum the water goes down the long brass tube inside *T*, where steam is formed which returns to drum through the short brass tube.

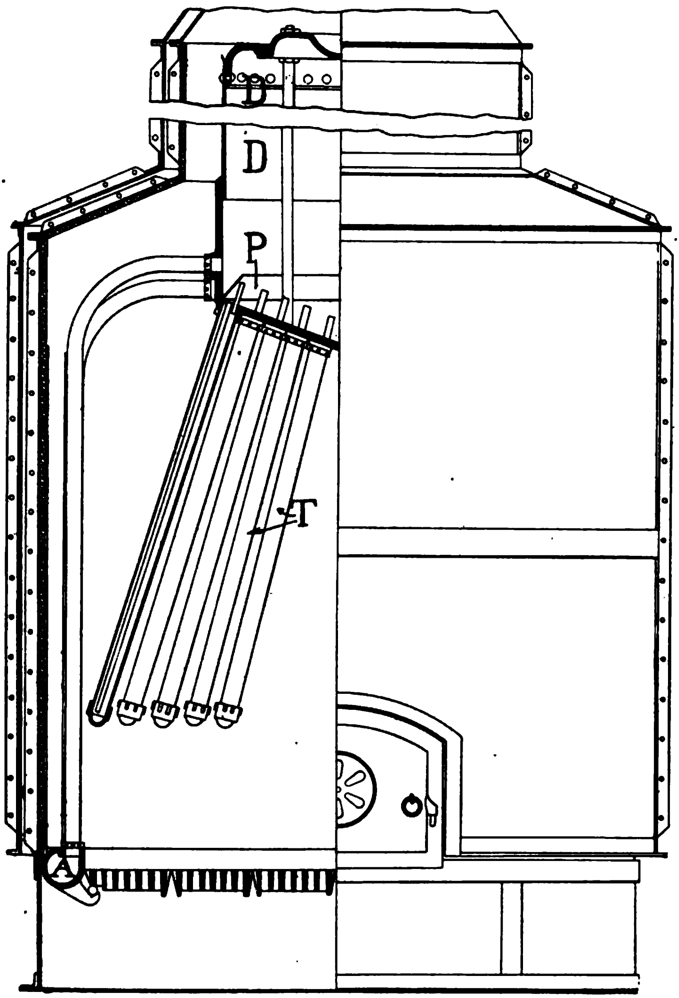


FIG. 43.—Ward Launch Boiler (Round).

Square Type.—Fig. 44 shows the outside of the Ward steam-launch boiler, square type. The principles involved are the same as

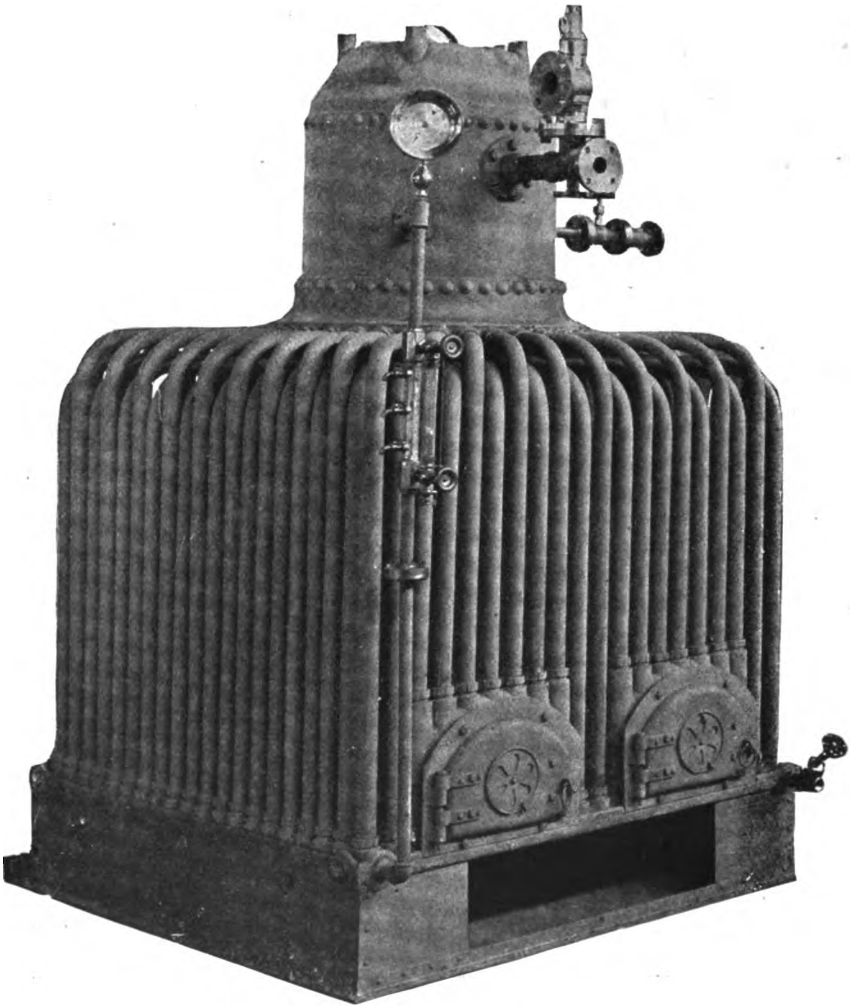


FIG. 44.—Ward Boiler (Square).

in the round boiler, the only difference being that the lower manifold is square.

Type W Launch Boiler.

The **Type W launch boiler,** which is being built for a new class of 50-foot steam launches, is shown in Plate XI. This boiler was designed in the Bureau of Steam Engineering, and is built at the New York Navy Yard.

It has a steam drum and two water drums, connected by slightly bent generating tubes. The outer row of tubes in each nest acts as a downcomer, the feed water being directed into them from the internal feed pipe, as shown at *A* in side elevation.

The **water circulation** is down the outer row of tubes to the water drums, and up the inner rows of tubes, as steam and water, to the steam drum. To aid the water circulation, by keeping the outer tubes cooler than the inner ones, baffle plates are installed between the middle rows of tubes in each nest; they extend from the steam drum about half way to the water drum, and from the front to the back of the boiler. These are shown in the transverse view.

Steam is drawn from the steam drum for use through the dry pipe near the top of the drum. There is a manhole in the front of the steam drum and a handhole at each end of each water drum. The boiler has a short grate with large heating surface. It has the fittings found on all large boilers.

The **circulation of the gases of combustion** is practically direct from furnace to smoke pipe.

CHAPTER IV.

BOILER FITTINGS.

The **fittings** * absolutely necessary on a marine, or, in fact on any boiler, are:

(a) On steam side of boiler:

1. Steam stop valves for regulating the flow of steam to the steam pipes or for closing the steam off the pipe.

2. Dry pipe in steam drum or shell for preventing foam or water from being carried into the steam pipes.

3. One twin or triple safety valve, set to lift at the desired pressure.

4. Steam gages for recording pressures above the atmosphere.

5. One set of three-gage cocks, arranged to show the approximate level of the water in the steam drum or shell.

6. At least two glass water gages to show the level of the water in steam drum or shell.

7. One air cock, placed at highest part of steam space, for letting the air out of the boiler as it is pumped up, or as steam is formed in the boiler.

(b) On water side of boiler:

1. Feed stop and check valves, for admitting feed water into the boiler, with internal pipes for its distribution, so that one part of the boiler will not be kept cooler than another.

2. Surface blow valve, internal pipe and scum pan, for removing grease or foam from the surface of the water in the drum or shell.

3. One or more bottom blow valves, for removing dirty water, sediment or loose scale from the bottom of the shell, water drums or uprights, for blowing down the boiler to reduce the saturation of the water when it gets too high, and for drawing off the boiler water by a pump. In fire-tube boilers and in some water-tube boilers with long water drums, internal pipes are connected to the bottom blow valves.

4. One or more drain cocks placed for drawing all of the water out of the boiler at the lowest part of water space.

5. One connection for drawing water from the boiler for test.

The boiler fittings will now be taken up and described.

Self-Closing Stop Valve, Closing toward the Boiler.—In the earlier designs, all boilers were fitted with one main and one auxiliary stop valve, connected, through openings in the shell of the boiler or steam drum, with the dry pipe. In later designs, these two

* **Specifications for boiler fittings will be found in Appendix.**

valves are in the same casing, thus requiring only one opening to be cut in the shell. In the recent large ships with water-tube boilers, where the main steam pipe takes steam from the boilers only indirectly, by way of the auxiliary pipes, there is only one stop valve on the drum, which is called the main stop valve. An automatic stop valve is fitted in the auxiliary pipe from the boiler to the main steam line near where the former joins the latter.

In the older ships, with fire-tube boilers, these steam stop valves were self-closing toward the boiler.

The ordinary form of self-closing valve, with part of the gear for working it from the deck, is shown in Fig. 45. *G* is the valve chamber, with inlet at *I* and outlet at *O*, in this case at right angles to *I*.

The lower view is a vertical section through the center, and the top one, a plan of the outside with parts omitted for clearness.

The valve *V* is secured to the valve stem *S*, as shown in the sketch. A short distance above the top of the stuffing-box, *S* is reduced in diameter and ends at the cross-bar handle *H*, which is pinned to it. The hand wheel *W* does not, as in the ordinary stop valve, raise and lower the valve, but only regulates the amount of opening which may be given to the valve.

Surrounding the reduced part of *S* is a threaded sleeve *F*, which may slide on *S*. The thread on *F* works in that of a bushing *N*, which may turn in the steel yoke *E*, but is prevented from rising by the flange or collar which bears against the under side of *E*. The bushing extends to the under side of wheel *W*. Between *W* and the top of *E* is the bevel wheel *B*, which is screwed on and keyed to the bushing, and to which is bolted the hand wheel. Geared to *B* is the bevel wheel *C*, which can be turned by the small shaft *D* leading to the deck. *D* turns in and is supported by a bracket bolted to *L*. Yoke *E* is held in place by two studs screwed into the bonnet *L* of the valve. On these studs slides a forked guide, not shown, which is secured to the lower end of *F*. This guide keeps *F* from turning, but allows it to have sliding motion on *S*.

When *W* is turned, either by hand or by means of the bevel gear, bushing *N* turns, and sleeve *F* will, therefore, move along *S*, rising into the opening *A* at the top of *N*. When *F* has been moved the required distance, stem *S* and the valve are pulled out, or the valve is *opened*, until the enlarged part of *S* is stopped by *F*. When the valve is being opened, handle *H* should always

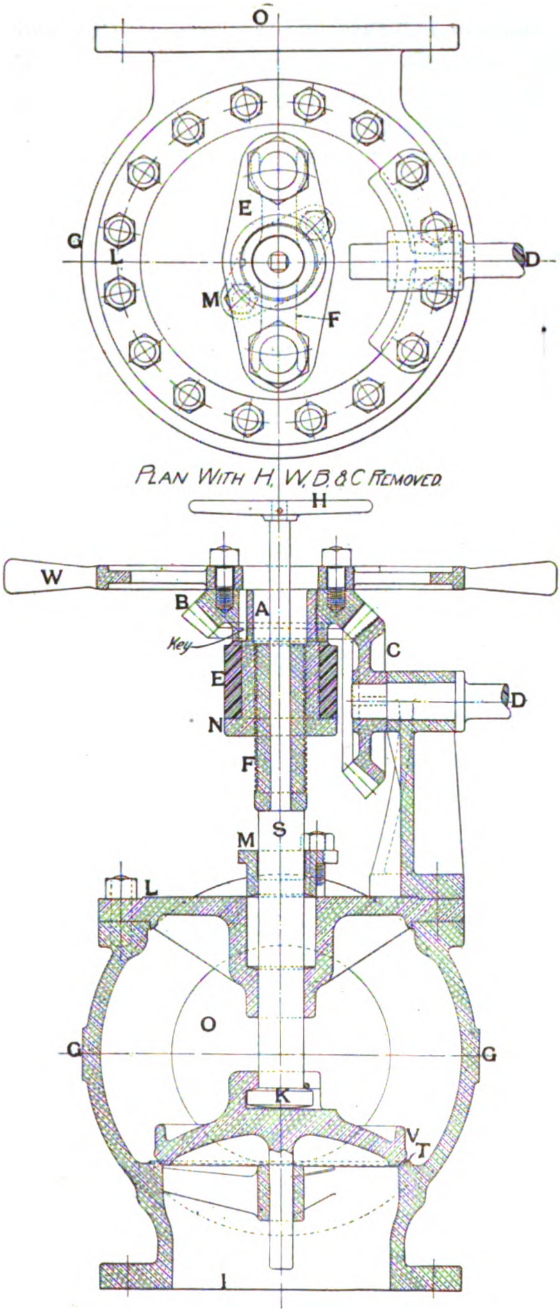


FIG. 45.—Self-Closing Stop Valve, Closing toward Boiler.

be pulled out as *W* is turned, in order to prevent the violent opening of the valve when the excess pressure under it is great enough to overcome the friction in the stuffing-box. As a safety precaution it is always well to have the pressure in the boiler a few pounds higher than in the line to be connected; then the valve is sure to follow up the motion of the sleeve ***F***.

These valves are fitted to boilers and pipes in a horizontal position, when possible, so that the weight of *V* and *S* will not enter as a factor in their movement when differences of pressure occur on the two sides of *V*. If fitted in a vertical position, the movement of *V* may be a violent one, and large valves have been broken from this cause. They are, however, easier to keep tight when fitted vertically.

Ordinary Stop Valves.—In the old style of stop valve the seat of the valve was beveled. Lately the practice has been to make the valve seats flat. There are numerous makes and various types of valves in use. Fig. 46 shows an ordinary screw-down stop valve made by Jenkins Brothers, and illustrates the principles involved. This valve consists of the following parts:

1. Body.	7. Gland.	13. Valve stem.
2. Guide stem.	8. Yoke.	14. Gland stud.
3. Disc nut.	9. Wheel.	15. Yoke stud.
4. Seat ring.	10. Wheel nut.	16. Lock nut.
5. Disc holder.	11. Jam nut.	17. Disc.
6. Cotter pin.	12. Yoke nut.	18. Disc plate.

Nos. 1 and 8, in the table above, are made of cast steel, cast iron or composition, depending on the service required; composition can be used in case of water valves or valves in lines carrying saturated steam; cast steel can be used with saturated steam; cast-iron valves are not used aboard ship, but are used extensively on shore for various purposes.

The other items in the table, except the yoke studs, are made of composition or Monel metal. The yoke studs are of composition or steel.

The operation of this valve can be easily understood from the sketch. It will be noticed that both the seat and disc can be renewed. The introduction of flat seats is due to the fact that, with modern high pressures, the bevel form of valve, having a small seating area, was quickly eroded by the flow of steam when opening or closing

the valve. The flat valve has a larger seat area, and the erosion takes place only on the inner edge of the seat and outer edge of the valve. In addition, the flat valve accommodates itself more readily to the varying expansions of the valve and seat and remains tighter under temperature changes than the conical valve.

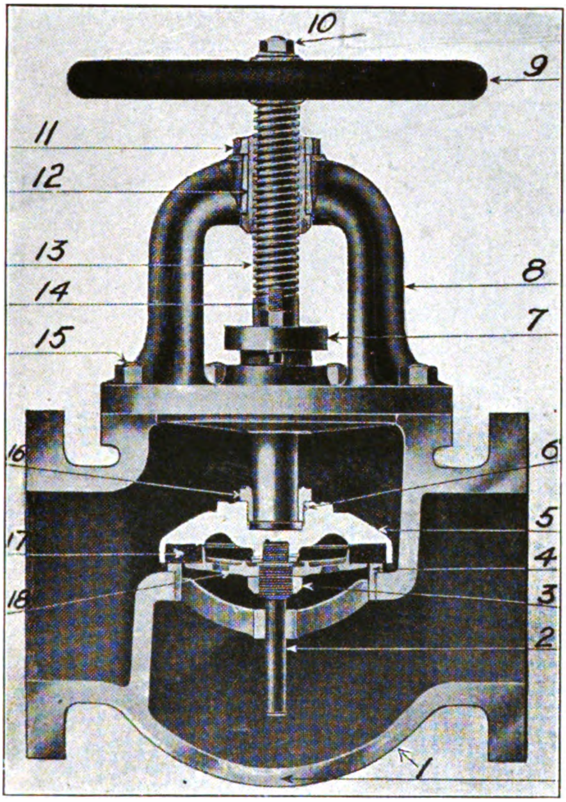


FIG. 46.—Ordinary Stop Valve.

These valves are always installed in such manner that they seat against the pressure. In the naval service they are made to close right-handed, *i. e.,* in the direction of the hands of the clock. Where used as stop valves on boilers or as engine stop valves, gearing is fitted to open and close the valves from the deck overhead, and from floor plates of engine- and fire-rooms. Large valves of this class are fitted with bypasses to equalize the pressure on both sides of the

valve before opening. Such a bypass is shown at *M,* in line sketch, Fig. 47. The line sketch of Fig. 47 is added to show the usual measurements required in ordering valves.

Fig. 48 shows a screw-down globe valve, fitted for screwed pipe connections, with flat valve face, renewable seat, the valve disc being fitted to project through the opening below valve seat. This disc prevents steam from blowing through and cutting the disc and seat as the valve is leaving the seat when being opened.

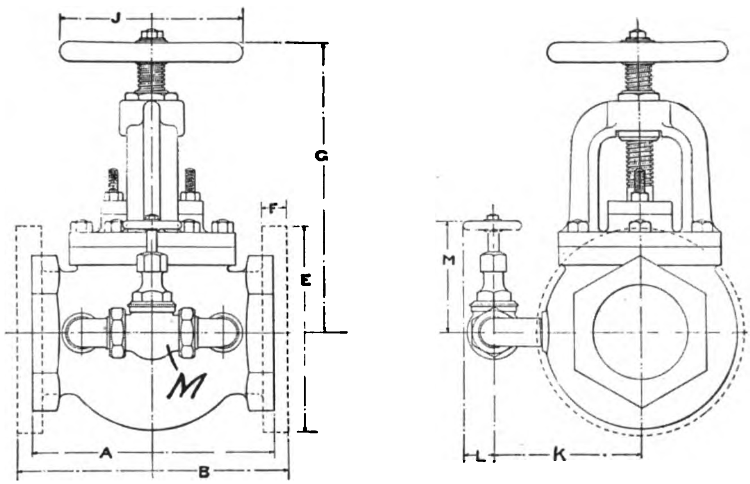


FIG. 47.—Bypass Valve.

A—Face to face, screwed.
B—Face to face, flanged, standard flanges.
E—Diameter of standard flanges.
F—Thickness of standard flanges.
G—Main valve, center to top of hand wheel, open.
J—Diameter of hand wheel.
K—Center of main valve to center of bypass.
L—Center of bypass to extreme outside.
M—Height of bypass, open.
N—Size of bypass.

The metal of the body and disc of the valve is composition, and the seat is hard, close-grained nickel.

Dry Pipes.—In each boiler or steam drum, a thin steel pipe is fitted as near the top as possible. This pipe extends nearly the length of the boiler or drum, and is perforated on its upper side with slits or holes, of such number and size that the sum of their areas is equal to that of the steam pipe leading from the boiler. Usually

one end of this pipe is secured to the stop-valve nozzle and the other end is closed. Steam from the boiler can, therefore, get into the stop-valve chamber only by rising nearly to the highest point in the steam space, and thence through the slits in the top of the dry pipe. As this pipe extends nearly the whole length of the boiler, the steam is collected from all parts of the steam space instead of rushing up from one place into the large stop-valve

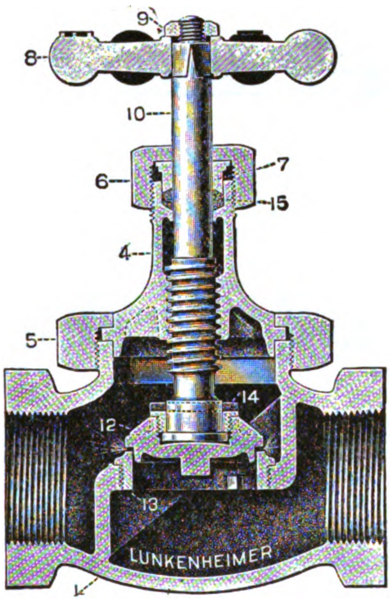


FIG. 48.—Globe Valve, Small Type.

nozzle. The evaporation is, therefore, more uniform, and any tendency to priming is much reduced. For the same reason, safety-valve chambers are now connected to the dry pipe, either directly or through the stop-valve chamber, instead of opening directly into the steam space.

One or more small drain holes are made in the under side of the dry pipe to prevent accumulation of water.

The dry pipes and drains to the steam drums must be examined frequently to ascertain if the holes in them are clear.

T-Casting for Steam Distribution.—Fig. 49 shows a T-casting, which reduces the number of holes to be cut in the boiler shell for the various stop and safety valves to one, all valves taking steam from the dry pipe.

G is the boiler shell, to which is riveted the nozzle *F*, which forms a seating for the casting *E*. *F* also strengthens the shell to compensate for cutting the hole. To the internal spigot of *F* is fitted a vertical branch *H* of the dry pipe, the latter being horizontal and closed at both ends. *A* is the flange to which the

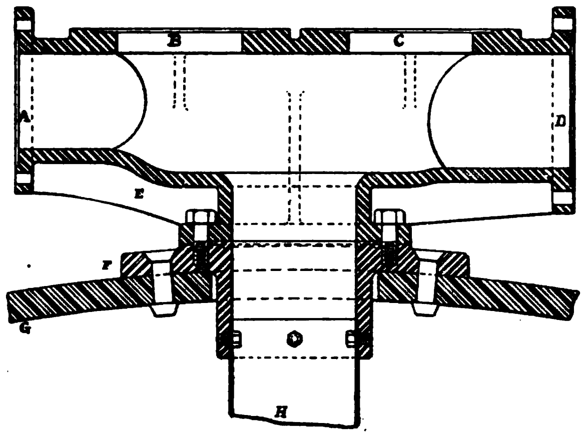


FIG. 49.—Steam Connection to Dry Pipe.

dynamo stop valve is bolted, and *D* that for the auxiliary stop valve, both self-closing, with their spindles horizontal. *B* is the seating for the main stop valve, and *C* that for the safety valves. The spindle for the main stop valve is, in this case, vertical.

These T-castings are installed on many of the ships now in the naval service. The *present* practice is to have a boiler opening for each fitting, with the number of fittings reduced to the lowest number practicable. The practice varies somewhat at the various shipbuilding plants.

Feed Stop and Check Valves.—The latest types of these valves are fitted with an internal pipe to discharge the feed water up toward the steam space.

Each boiler has two of these combined valves, entirely separate from each other, one connecting the boiler to the *main feed pipe,* and therefore called the *main check valve,* and the other to the *auxiliary feed pipe,* and called the *auxiliary check valve.* Except for steam launches, two valves are always provided, for safety, in case one of the feed systems should fail to work.

Fig. 50 shows a recent form of check valve. Between the check valve *K* and the drum *O* there is the stop valve *G*, by means of which communication with the boiler can be shut off, thus allowing the check valve to be overhauled, if necessary, when steam is on the boiler.

The valves are in the composition chamber *H*, with inlet for the feed water at *Q* and outlet through the nozzle at *L*. The

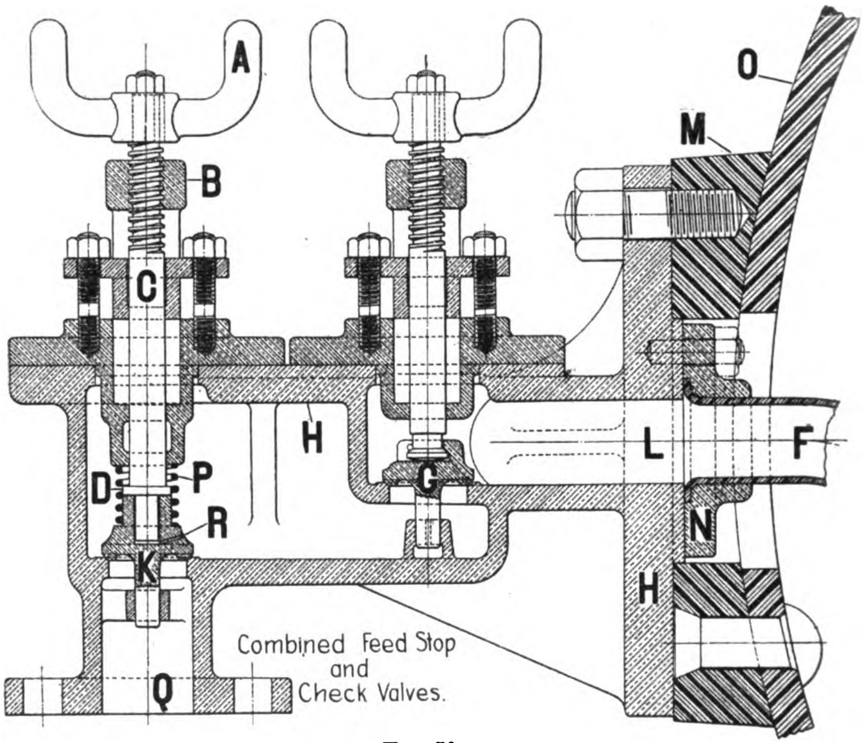


FIG. 50.

check valve *K* can move up and down freely, the amount of movement or *opening* being regulated by the collar *D* on the valve stem *C* and handle *A*. *B* is the yoke. *N* is a standard bronze flange. *F* is the internal feed pipe by which the water is led to the point or points of delivery.

In the figure, the stem is shown screwed down to close the valve entirely. The valve is guided below the spindle and above by the

socket, in which the short cylindrical projection of *C* can move freely. The phosphor bronze spring *P* helps to close the valve when feeding.

When steam is on the boiler, the stop valve *G* is kept open and the boiler pressure will then be on the back of valve *K*, and keep it shut. When the boiler is to be fed, *A* is turned slightly, thus raising the collar on *C* a certain distance and leaving a space between it and the top of the valve *K*. The valve can now lift through that distance whenever the pressure below it in the feed pipe is greater than that on the back. This will happen during the early part of the stroke of the feed pump; towards the end of the stroke, as the pressure decreases, the valve will be forced down by the boiler pressure and spring. This alternate opening and closing of the valve with the strokes of the pump produces an audible click. If this is not heard, the check valve is not working properly and should be examined. Should the feed pipe near the valve chamber be very much hotter than the rest of the pipe, it is evident that the check valve leaks. Small holes *R* are drilled at the bottom of the guide or socket on *K* for the escape of water as the valve lifts.

In fire-tube boilers, the internal feed pipes run along the length of the boiler above the tubes, the main pipe on one side and the auxiliary pipe on the other.

In water-tube boilers, as in Fig. 50, the feed check and stop valves are on the steam drum, and, owing to the height of these drums above the fire-room floor, gear for working the valves from the floor plates is provided. This hand gear is shown in Fig. 50b.

The bottom of the outlet nozzle *L* is always well above the seat of *K*, to ensure a water seal on top of the valve. The stems of

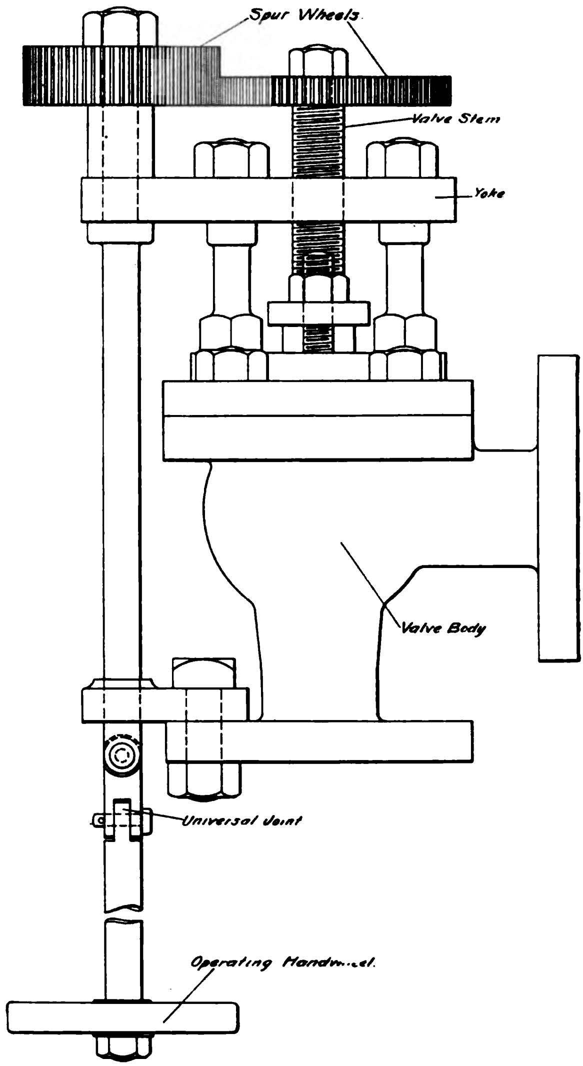


FIG. 50b.

both check and stop valves, like all other valves on boilers, have screw threads outside of the valve chamber.

In order that the amount of feed water supplied can be regulated for each boiler separately, without varying the speed of the feed pump, the latter is fitted with a relief valve.

Feed Check Valve for Steamers.—Fig. 51 shows a section of a simple form of check valve which is sometimes fitted to the feed pipe of steamers and other small boilers. It is also frequently used in pipes to prevent the return of the water.

The valve swings on a pin, which can be removed by unscrewing a plug in the side of the chamber. As will be noticed, the valve will open only to let in water from the left, into which end is screwed the discharge pipe of the feed pump. The right-hand end is screwed on a nipple in the boiler, and the back of the valve is held down by the boiler pressure.

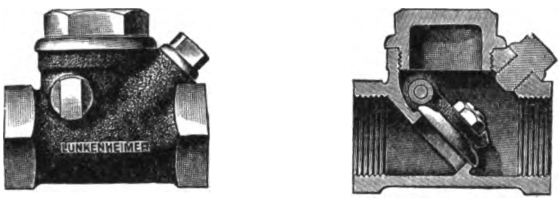


FIG. 51.—Feed Check Valve.

When the valve is to be examined, the top cap is unscrewed. Should the valve leak, it can be ground and fitted to its seat by inserting a grinding tool through the inclined hole on the upper side, after removing the plug there.

Internal Feed Pipes.—The internal feed pipe is an extension into the boiler of the external feed pipe. It is necessary in order to carry the inflowing water clear of the metal in the vicinity of the opening and distribute it evenly in the drum or shell, so that air and other injurious ingredients in it will not corrode the metal around the opening.

The latest method of installing the internal feed pipe is to lead it along nearly the entire length of the drum, with its top about 6″ or 7″ below the normal water level when steaming, with the openings upward so that the water will be discharged into the water space about the middle of the drum. This arrangement forces the air entering with the feed water toward the steam space and lessens greatly the quantity of air circulating through the boiler.

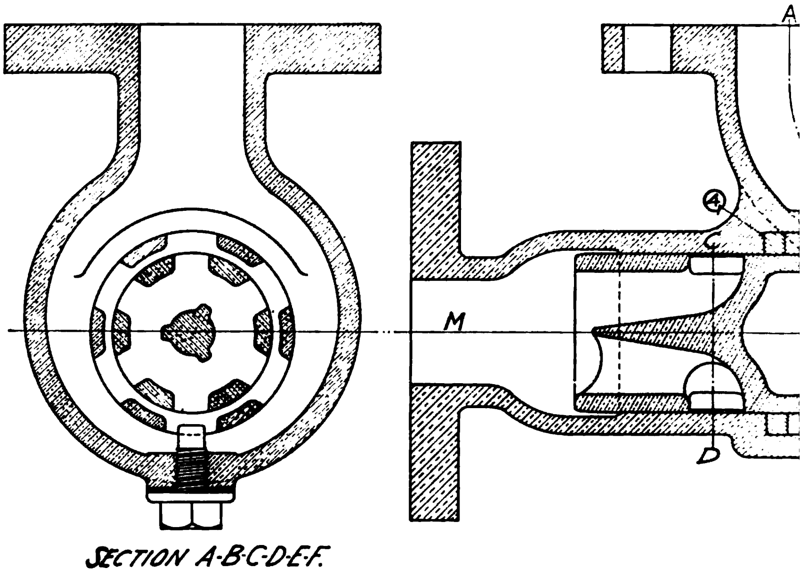


FIG. 54.—Seatless

Surface Blow Valves.—Ordinary screw-down globe valves made extra heavy are used for surface blow valves. These valves close against the boiler pressure.

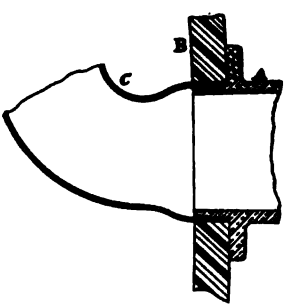
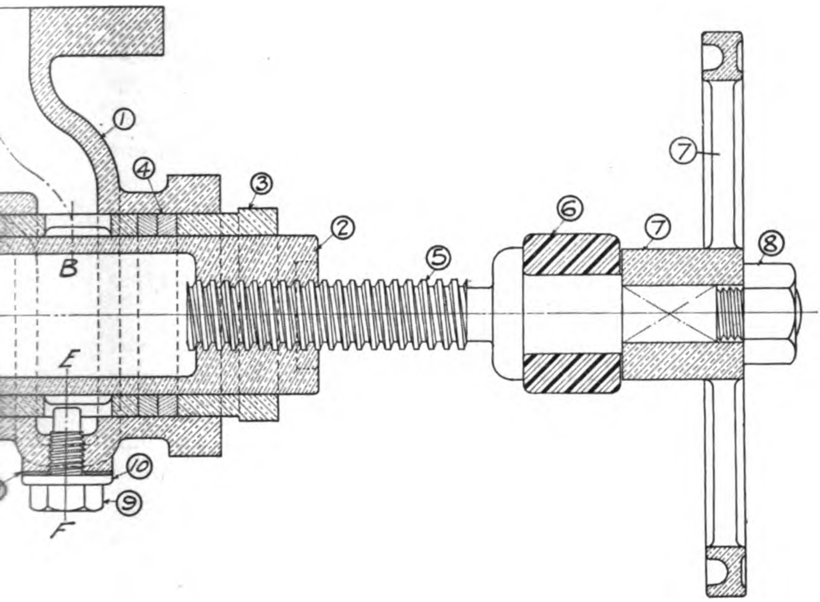


FIG. 53.—Method of Fitting Internal Blow Pipe to Valve.

Fig. 53 shows the method of fitting the internal blow pipe *C* to the valve casting *A*. The latter has a nipple or spigot which projects through the shell of the boiler or drum *B*, and makes a tight fit with the pipe which has been expanded into the shell. The valve is secured by bolts, not shown, passing through the shell and the valve flange.

The latest method of installing the surface blow pipe is to lead it along the entire length of the drum in a position where the water in the drum has the least motion. It is placed about 2″ below the normal water level of the drum, and has slots on the upper side along its entire length.

Bottom Blow Valves.—Specifications for the battleships *New York* and *Texas* call for 1½″ bottom blow valves on each boiler, located where approved; to be of the seatless hollow piston type without any projection upon which sediment or scale can accumulate; the pressure to be against the side of the piston, when closed;



ttom Blow Valve.

the piston to have an opening in the side, which, when the valve is open, will present a full unrestricted area for blow-off. The term "seatless" is a trade name for a type of valve which does not depend for its watertightness on a valve fitting a seat. Packing around a piston accomplishes this.

Such a valve is shown in Fig. 54. The flange *A* bolts to the upright or water drum. Pressure is on the piston 2, around the whole of its circumference, through the opening in valve body at *BE*. The piston is hollow from *CD* to its outer end, with openings at *CD*. It is moved by the hand wheel 7, turning the valve stem 5, which works loosely between the wheel and collar through the yoke 6. The valve stem is threaded at 5, and moves the piston 2 by screwing through it, 2 being prevented from turning. The two turns of packing at 4, on each side of the opening *BE*, on the valve body, make the joint between the piston and valve body tight. The gland 3 sets up on the packing at 4 and (through the distance piece) at 4. The studs to hold the gland in position are not shown.

All of the discharges from the surface and bottom blow valves join in one common discharge to the sea through an independent sea valve. The valve is opened by working the hand wheel until the opening at *CD* comes in line with *BE*, when the water will be blown out at *M*.

Formerly, when salt water was used for make-up feed, the *bottom blow valve* was also used to blow out the denser brine from time to time, and this, by permitting the introduction of new and less concentrated sea water through the feed valve, helped to keep the concentration of the water in the boiler below the required limit. It was also used to *blow down* or blow all of the water out of the boiler, when through steaming and after the fires were hauled. The U. S. Naval Instructions for the Care, Preservation and Operation of Boilers prescribe the limits of concentration in the various types of boilers below which the bottom blow should not be used.

It often becomes necessary to get rid of mud or other sediment from dirty fresh water, and for this purpose the bottom blow may be used while the boiler is under steam. This is especially necessary in water-tube boilers. The Babcock and Wilcox Company recommend that the bottom blow be used at least twice a day when steaming regularly, by opening the valves wide and immediately closing them. A more frequent and freer use is recommended when the boilers are under banked fires or steaming slowly, as, on account of the less active circulation under these conditions, there is greater opportunity for deposits to settle on the heating surfaces.

The bottom blow valve also serves another purpose. Through a pipe connection, leading from the blow pipe in each compartment to the auxiliary feed pump, the water in any boiler may be pumped out, by opening the bottom blow valve, after steam is off the boiler, and discharged overboard or into the reserve tanks or boilers.

Safety Valves.—These are fitted to prevent the pressure in the boiler from rising above the safe working limit and to provide a ready and automatic means of escape for the surplus steam. This is accomplished by opposing the resistance of a spring, acting on one side of a valve, to the steam pressure in the boiler acting on the other side, the chamber into which this valve opens being connected to the atmosphere by the escape pipe.

Figs. 1 and 2, Plate XII, show examples of duplex pop safety valves of the navy pattern, the first showing an outside and a sectional view of the valve made by the Star Brass Manufacturing Company, and the second, a sectional view of the improved valve made by the American Steam Gage and Valve Company. The general appearance of the outside of the American valve and its lifting levers and shaft is similar to that of the Star valve, so that only one outside view is shown.

These valves, as well as those made by other manufacturers, conform to the requirements of the Bureau of Steam Engineering. The type shown here is called the "Duplex," on account of two valves being enclosed in one casing. They are also made in the single, triple and quadruple types, but the valves are the same for all types of the same make. The usual requirement is that two or more safety valves shall be fitted, instead of having the necessary area put into one valve. The valves are, whenever possible, placed vertically. When placed horizontally, owing to the play between the wings of the valve and the seat, they are very hard to keep tight.

Referring to Plate XII, *A* is the valve casing, its lower part *C* having usually a separate and direct connection to the boiler, and its upper part being connected to the escape pipe by the flange *B*. When *C* is connected to the main stop-valve casing, it must be between the boiler and the stop valve. In both cases, steam is taken from the dry pipe.

Bolted to the top of *A* are the two cases *W, W,* for the springs, each being so fitted that the valve *V* can be taken out without interfering with the adjustment of the spring *P*.

To move the valve by hand, the lever *L,* working against the cap *E,* which is secured to the valve stem *T,* is provided. By means of the link and arm shown, *L* is connected to a rock shaft *Q*. This shaft is turned by suitable lifting gear, either from the fireroom or from the deck above, the rock shaft arms being so arranged that the valves in each casing are lifted in succession and not together. By means of the handle secured to the valve stem *T,* the valve *V* can be turned on its seat *S* without interfering with any other part. Any scale or dirt which may have lodged between the valve and seat can thus be removed. To prevent an accumulation of water from the condensation of escaping steam, a drain pipe leading into the bilge is attached to the opening *M* below the level of the adjusting ring *X*.

The Spring.—The spring *P* is of the highest quality of steel, nickel-plated, and square in section. It is enclosed in the case *W,* to prevent contact between it and the steam and so reduce the chances of corrosion. Each spring is made long enough to allow the valve to lift *one-eighth* of its diameter when the valve has been set at the designed working pressure. To overcome the effect of any tilting of the spring when the valve opens, and consequent

binding of the wings of the valve against the sides of the seat *S*, the ends of the spring must be free to oscillate. This is accomplished in the American valve, Plate XII, Fig. 2, by inserting the independent flanges *F, F,* which have spherical bearings where they rest against the valve stem *T*.

In the Star valve, Plate XII, Fig. 1, the lower flange *G*, called the *compression plate,* is pivoted on the valve, and has two projections which fit into slots cut out of the screw ring *H*. These slots permit the ends of the projections to move up and down when the spring tilts, without communicating this motion to the valve, the wings of which, therefore, remain truly in line with the sides of *S*. When the valve is to be examined, the slots in *H* allow the case *W*, valve stem *T*, spring *P*, and compression plate *G*, to be lifted out together, the valve *V* remaining on its seat. In the American valve, Plate XII, Fig. 2, the valve *V* is lifted with the spring, to be disconnected after removal by taking out the small set-screws and unscrewing the small nut shown on top of the valve.

The casings *A* and *W* and valves *V* are made of standard composition for strength and to prevent corrosion. The valve stem *T* is made of rolled bronze. The springs are adjustable for pressures up to the test pressure of the boiler.

The Valve.—The valve seat *S* is a solid nickel casting screwed into the casing *A*, and extends down to the bottom of the wings on the valve *V*. It is turned to a cylinder on the inside and serves as a guide for the wings of the valve these being slightly smaller in diameter to prevent binding. On the top of *S* a narrow conical seat is turned to an angle of 45° for the face of the valve *V*. Around the outside of the top of *S* there is a screw ring *X*. Valve *V*, with its wings in the cylindrical part of *S*, rests on the conical seat, and is held in place by the valve stem *T*, which fits loosely in the valve, as shown, the bottom of the stem being below the level of the valve seat. As will be noticed, the valve extends beyond the face in a sort of projecting lip, the size and shape of which, as well as those of the upper face of the adjustable ring *X*, vary in the different designs of valves. The object and necessity of the lip and ring will now be explained.

Suppose *V* to be an ordinary valve with a conical face just covering the seat. The spring *P*, being under compression to resist a certain pressure, would allow the valve to rise only slightly for an instant when that pressure is reached, as the resistance of

the spring to still further compression increases with the amount of that compression. The valve would, therefore, open and close continuously, discharging only a little steam each time. But, if the face of the valve is enlarged beyond the seat, it will be readily understood that, as soon as the valve opens to the pressure, the escaping steam acts on an increased area; therefore, the opening for the escape of steam is increased suddenly, and the valve "pops" and is held open until the pressure has fallen below the opening pressure. To prevent too great a drop in the pressure before the valve closes, or, in other words, to reduce the difference between the *opening* and *closing* pressures so that it shall not exceed 5 pounds, the adjustable ring *X* is provided in connection with the deflecting lips. By means of this ring, the opening for the escape of the steam, after the latter has been deflected by the lip, can be slightly changed, and the closing pressure regulated.

X in the Star valve, Plate XII, Fig. 1, is a screw ring with teeth on its outer circumference. By taking out the screw stop *O* and inserting a pointed rod between the teeth, the ring can be screwed up or down. In the American valve, Plate XII, Fig. 2, the ring is not threaded, but is moved up and down by two screws, one of which is shown at *N* (the other one being diametrically opposite), which engage with the ring by means of collars. This arrangement is similar to the ordinary stuffing-box gland.

Lift of Valves.—It was stated above that the spring must be long enough to allow the valve to lift one-eighth of its diameter when set at the working pressure. This must not be mistaken for the actual distance that the valve lifts when blowing, as this rarely exceeds $\frac{1}{8}''$. The area of the valve is calculated for a lift of only $\frac{1}{10}'$ when blowing at the full steaming power of the boiler. If the spring were short, so that it would allow only $\frac{1}{8}''$ or $\frac{1}{10}''$ movement and no more, it would soon become permanently set. But, by making the spring longer, so that the valve, say a 3″ one, can lift one-eighth of 3″, or $\frac{3}{8}''$, the required $\frac{1}{10}''$ or $\frac{1}{8}''$ movement of the valve will be always within the elasticity of the spring.

To guide the upper end of the valve when it lifts, the valve casting is extended in a cylindrical shape, which permits it to slide in the cylindrical bottom end of *W*. A liner *K* is shown in *W* in the cut of the Star valve, Plate XII, Fig. 1, which is not put in naval valves, as everything is of composition.

Resetting Valves.—When a change is to be made in the opening or blow-off pressure of the valves on a boiler, the fires are put in such condition that the steam pressure can be easily raised to the blowing-off point for a few minutes at a time. The caps *E* are taken off by unlocking and removing the pins or keys *I, I*. These pins not only prevent tampering with the adjusting heads *D*, but secure the handle to the valve stem. The details of the adjusting gear are not shown in the Star valve, and reference is therefore made to Plate XII, Fig. 2, but the description will answer for both.

The lock nut *J*, on top of case *W*, is slacked off and the adjusting head *D* is set to the new pressure desired, by screwing down on it to increase, and screwing up to decrease the blowing-off pressure. The index *R* on the Star valve and the graduations on the stem of the American valve show the positions of *D*.

The lock nut is now set up, and the steam pressure is allowed to rise for a short time so that the valves will blow or pop. Observe the opening and closing pressures by the steam gages on the boiler. If the valve does not reseat promptly (at about 5 pounds below lifting pressure), the ring *X* must be moved further away from the lip of the valve. Where there is more than one safety valve on a chamber, set one valve at a time, having the others "gagged" while one is being set.

Fig. XIIb is a *gag*. The hooks *H, H* are set under the compression nut, and the bolt *B* is screwed down on the top of the stem.

When both opening and closing pressures have been satisfactorily adjusted, secure the screw stops *O, O* in the Star valves and then replace caps *E* and the handles, and lock them in place.

While it is preferable to set the valves by steam, it can also be done by filling the boiler with water, disconnecting the main escape pipe, and watching for the valve to lift as the pressure is put on from the main feed pump.

Lifting Gear.—Besides the automatic lifting of the valves by steam pressure, mechanism is always fitted so that the valves can be raised by hand from the fire-room, or from a passageway outside of the fire-room, or from the deck above. The last two connections are emergency ones, for use in case of accident when it is impossible to work the valves from the fire-room.

Care and Overhauling of Valves and Lifting Gear.—In order to ensure the proper working of the valves and the gear, the Naval Instructions require that the hand lifting gear shall be thoroughly tested at least once each week, whether the boiler is steaming or idle, and if the boiler is steaming, the valves shall be lifted weekly by steam pressure also. Should the gear work hard, the joints should at once be overhauled, cleaned and oiled. As a further precaution, these joints should be disconnected and thoroughly overhauled at least once in six months. The threads of the raising screw, being more liable to accumulation of coal dust, on account of the oil or tallow used to lubricate them, require particular attention.

Steam Gages.—Each boiler has attached to it one or more gages by means of which the steam pressure is indicated. Fig. 55 shows one of the types usual in the U. S. Navy, with the screwed bezel, or front, the glass cover, and the dial removed. For boilers working at 160 to 180 pounds pressure per square inch, the dial is usually

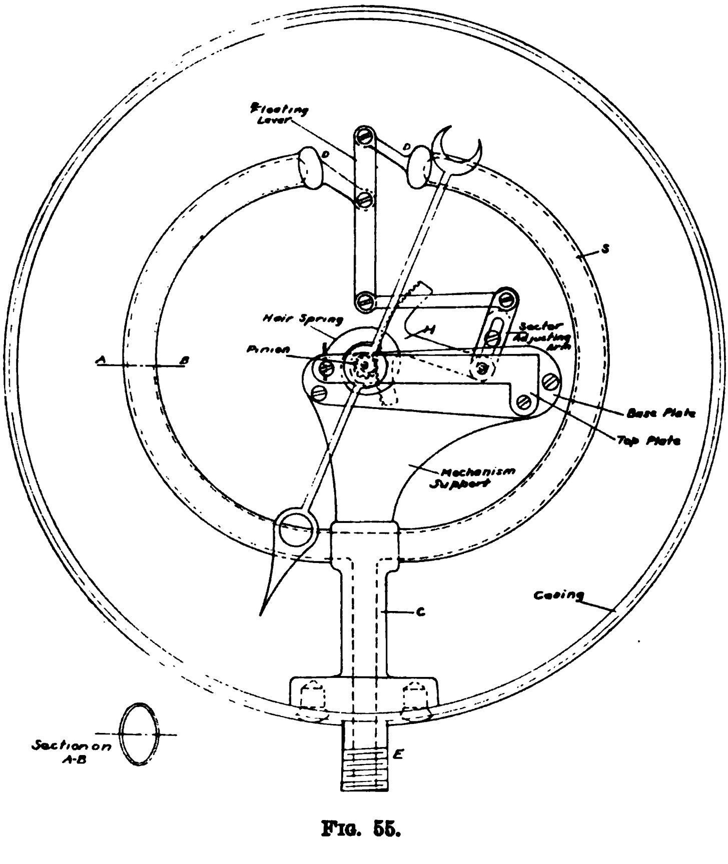


FIG. 55.

graduated to 240 pounds. For higher pressures, the springs are stronger and the dial is graduated sometimes as high as 500 pounds.

The double Bourdon spring *S* is made of seamless-drawn tubing, elliptical in section, and either plain or corrugated. The upper ends *D, D* are closed, and the lower ends open into the hollow socket *C,* which, at *E,* is connected by a pipe with the steam space of the boiler.

Base and top plates are secured to the mechanism support as shown. The pinion spindle, and the spindle of sector *H*, are held between these two plates. The pointer is held on the upper end of the pinion spindle with a friction fit. By the system of levers, one end of which is connected to the ends *D, D* of the spring *S*, and the other to the toothed sector *H*, any motion of *D* is multiplied and transmitted to the pinion on the axis of the pointer and engaging with *H*.

The spring *S* being elliptical, with the longer diameter perpendicular to the curvature of the spring, any increase of pressure on the inside will tend to equalize the diameters of the ellipse, and thus cause each tube to straighten, that is, move the closed ends away from each other. The diameters of the ellipse will tend to equalize, because any pressure inside the tube tends to make the tube take its greatest cross-sectional area, which, for a given length of periphery, is the circle. Any shape of cross-section, not a circle, would have the same effect, but it is apparent that the ellipse is most advantageous. This can be easily understood by folding a strip of paper on itself several times, closing one end and rolling up the folded paper. Blowing into the open end will straighten out the roll. The elasticity of the metal of the springs, if not exceeded, will bring the ends back to their normal position when the pressure is decreased. The hair-spring keeps the joints of the mechanism pulled in one direction, preventing lost motion. A small pin on the dial stops the pointer at a little above zero. The springs are of such shape and strength that no permanent set is acquired under any pressure shown on the dial. All interior parts are made of non-corrosive materials, and the movement is made as light as possible. The casing is made of brass, nickel-plated.

To prevent the ill effect of actual contact of the steam with the springs, all gages intended for steam must have a siphon fitted to them below *E*. The siphon is made by bending a complete circular loop in the pipe leading to the boiler. In order that it may be effective, the siphon is made sufficiently large to contain enough water to fill both springs when under pressure, and so fitted that this water seal will not be drawn out of the siphon when the pressure is off. A small cock, by which the gage can be shut off, is fitted between the siphon and the gage.

The dial is graduated for every 5 pounds by comparison with a mercurial column. To make sure that the boiler gages give

reliable indications, they must be tested at least quarterly on naval vessels by comparison with a standard gage, which is kept correct by frequent tests and is used only as a test gage.

Gage Cocks.—In addition to the water gages, each boiler or steam drum is fitted with several *gage cocks,* each attached independently and directly. In double-ended boilers, each end is fitted with these cocks. They are spaced equally in a vertical direction, about 6" in fire-tube and 3" in water-tube boilers, the lowest one in fire-tube boilers being about 4" *below* the highest heating surface. By opening each cock in succession, an experienced man can tell, from the steam or water blowing out, approximately where the water level is, and thus check the indications of the glass gages. These cocks are fitted with levers and rods, where necessary, to work them from

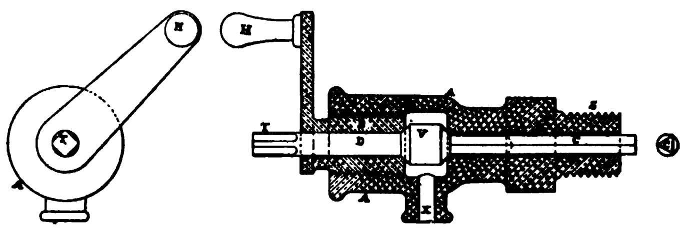


FIG. 56.—Gage Cocks.

the fire-room floor, and with a drip pan and a drain pipe leading to bilge.

The gage cocks should be tested every watch, and at a time when the gage glass is known to give an accurate indication of the water level. The *appearance* and *sound* of the blast from each cock should be noted, and be used as criteria in case of subsequent failure of the gage glass.

Fig. 56 shows a pattern used in our navy. *A* is a composition valve chamber which is screwed into the boiler or drum by the gas-pipe thread *S*. The valve *V,* its spindle *D* and guide *C* are turned from one piece of rolled manganese bronze or Tobin's metal. The guide *C* is triangular in section, and the spindle *D* is circular where it passes through the movable seat *B,* and square at the end *T*. The valve has two faces. The inner seat for the valve is formed in the casting *A,* and the outer one in the block *B,* which can be screwed in and out by the handle *H*.

The valve is closed by screwing in *B*, and opened by the steam pressure when *B* is screwed out. The opening of the valve is at least $\frac{3}{8}''$ in diameter, and that of the discharge at *X* at least $\frac{1}{4}''$. By a wrench at *T*, the valve can be turned and the passage around *C* be kept clear. The movable seat serves as a stuffing-box, but in a more efficient and safer manner.

Water-Gage Glasses.—These are fitted at the front, or more generally at the sides, of each fire-tube boiler, and on the side or head of each steam drum in water-tube boilers. Double-ended fire-tube boilers have two of these gages at the feeding end, placed as far apart as possible, and one at the other end. Fig. 57 shows a glass

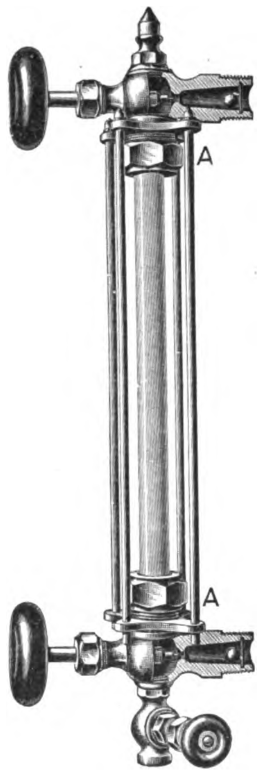


FIG. 57.

water gage without the wire-mesh guard, which is often fitted around the glass. All water gages must be automatic or self-closing.

The gage consists of an annealed glass tube, secured by stuffing-boxes to the top and bottom *shut-off* cock or valve chambers, the *blow-out* cock or valve at the bottom, and an automatic self-closing valve in the back of each shut-off chamber. On water-tube boilers, the whole gage is connected directly to the nozzles on the steam drum, the shut-off cocks being then frequently placed back of the

self-closing valve. On fire-tube boilers, the chambers are connected by pipes to the top and to near the bottom of the boiler, respectively, as in Plate I, each pipe having a stop valve on the boiler shell. From the blow-out valve a drain pipe leads down to the bilge.

The glass is ¾″ in outside diameter for all large boilers, and ⅝″ for small boilers, the exposed length varying from 10″ to 16″, and the whole length from 2″ to 2½″ more. One or two rubber rings, or *grommets*, around the glass near each end, set up by a washer and nut on each stuffing-box, make steam- and water-tight joints. These are shown at *A*, Fig. 57.

To prevent scalding of the firemen when a gage glass breaks, automatic self-closing valves are fitted. These consist, as shown in Fig. 57, of a small valve or ball, which is free to move within a chamber through which the steam or water passes from the boiler to the glass. So long as there is equilibrium of pressure within the water gage, this automatic valve does not move. But if the glass breaks, there will be a rush of steam and hot water into the fire-room, and, owing to the lower pressure on the opposite side, the valve will be forced against the seat provided. The amount of steam and water blown out will thus be very small, and the shut-off cocks or valves can be closed by hand without danger of scalding. A new glass can then be put in by slacking back the stuffing-box nuts. To catch any small pieces of glass, in case of breakage, a guard of wire gauze or heavy glass is often fitted around the glass.

Fig. 57 shows the Star gage glass with "ball" valves. The automatic valves are shown open; the shut-off valves are open. It will be seen that there is a seat for the automatic valve and another one, opposite this, for the shut-off valve. The ball in the Star gage rolls down the slightly conical surface when in equilibrium. The stem of each shut-off valve ends in a pin projecting beyond its seat, by means of which the automatic valve is pushed back to its normal position as the shut-off valve is closed. When the glass has been renewed, the shut-off valves are opened, and the automatic valves remain in place and leave the passage for steam or water open.

Where the water gages are too high above the fire-room floor, the wooden wheels are replaced by grooved metal ones, with knurled surfaces, which are worked from below by a continuous chain. When cocks are fitted, they are worked by levers and rods or chains, the latter hanging down to within easy reach.

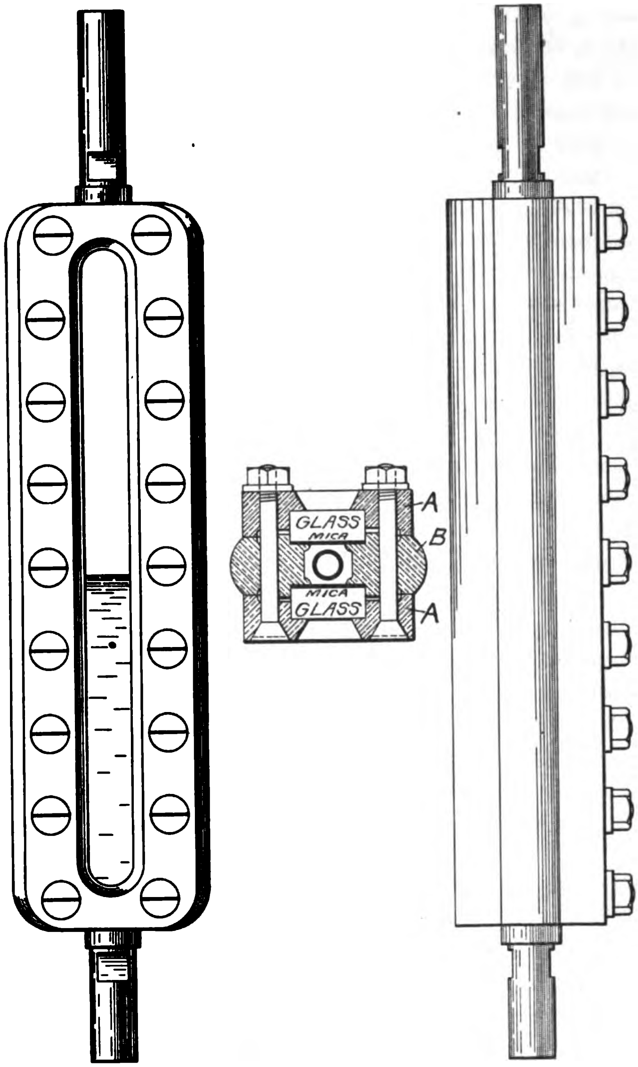


FIG. 58.—Dewrance Mica-Lined Water-Gage Glass.

Fig. 58 shows a Dewrance water-gage glass that is giving excellent results. This consists of two heavy outer frames *A* bolted to a center frame *B*. In recesses in the center and outer frames are secured two heavy glass plates, lined with a sheet of mica on the side next to the inner frame. These glasses are sufficiently far apart to allow a space for steam and water between them. All of the

water condensed in the upper arm of the gage drops down on the surface of the water, making the level very conspicuous. A light, arranged to shine through the glass from behind, makes the water level more apparent. The mica sheets protect the glass and are easily replaced; if the water wears away the mica and etches the glass, the glass can be ground and used again. The frame is heavy and rigidly supports the glass. This frame can be installed with any system of automatic water gages in the place of the glass in the water-gage stuffing-boxes.

Numerous types of water-gage glasses have been used. The two described above, however, illustrate the principles involved.

Location of Water Gages.—The gage must be so placed that the water tender may know that there is a safe amount in the boiler, so long as the water shows in the glass, and the glass must be long enough to show the level under all ordinary variations.

On fire-tube boilers, the gage is placed at such height that the lowest exposed part of the glass is at least 1″ above the top of the combustion chamber; the latter is usually shown by an index plate fixed close to the water gage. The working water level is usually from 6″ to 8″ above the bottom of the exposed glass. On water-tube boilers, the gages are so fitted that the middle of the glass is either below or at the center line of the drum.

Sometimes, instead of connecting the gages direct by pipes with the top and bottom of a fire-tube boiler, they are connected to a *stand pipe,* as in the English-built "Albany" and "New Orleans." This pipe is a hollow casting consisting of a vertical part with two horizontal legs. The latter are connected direct to the boiler shell, without valves, the center of each opening in the shell and the corresponding shut-off cock of the gage being nearly in the same horizontal plane. The column of water in the stand pipe, being outside of the boiler, and between it and the gage, is less exposed to the effects of rapid ebullition than the water inside the boiler. The indications of the gage will, therefore, be more reliable than if it were attached directly to the shell. The openings of the stand pipe are, however, too near the working level of the water, and any oily scum carried up with the steam will be more liable to get into and dirty the glass than if the gage were connected to the top of the boiler. When the boiler is forced much, the effects of the violent boiling of the water extend down to near the lower opening and cause unsteady indications in the gage. When the lower part of the gage is connected to the bottom of the boiler, where the water re-

mains almost quiet under all rates of steaming, no such unsteadiness can occur. The method used in our navy is, therefore, preferable.

Trying Gage Glasses and Cocks.—In order to make sure that the indication of the gage glass is correct, and to clear the glass and connecting pipes of oil or obstructions, the gage is tried frequently during a watch. The whole glass and upper pipe are blown through by closing the lower shut-off valve and opening the blow-out cock. Then, by closing the upper valve and opening the blow-out cock, the lower passage will be cleared. After these trials have been made, the water in the glass will resume its level quickly, if the glass is in working order. The gage cocks are then tried, and, if these indicate a serious difference, the glass must be blown through again. It often happens that a piece of scale or other matter closes the opening in the lower pipe. In this case, the indication of the glass would be altogether unreliable, and, if the opening be not promptly cleared, would become dangerously misleading by the rapid increase in level due to condensation of steam from above. If the top shut-off valve or the upper valve on a boiler under steam were closed, the glass would show full, as there would be no pressure on the water in it.

If, after blowing through several times, the glass does not work properly, the whole gage must be shut off by closing the stop valves on the boiler, the glass be drained, and then the shut-off valves be taken off. The automatic valve and part of the passages can then be examined and cleaned. If still unsatisfactory, the glass must be cleaned out and the grommets and passages below be overhauled.

When trying the upper cock of a gage fitted to a stand pipe, a possible error may be made. Suppose the passage in the upper leg of the stand pipe to be choked. The glass would still be in communication with the boiler through the vertical connecting part and the lower horizontal leg of the stand pipe. If now the upper shut-off cock is tried, as explained above, water would be forced up through the vertical part and down through the glass, thus seeming to indicate too much water in the boiler. As there are no valves between the boiler and stand pipe, the latter cannot be tried separately. To reduce the chances of their choking, the stand-pipe passages are made large, and the probability of the above error being made is, therefore, very small.

Every water tender should blow through and test all the gage glasses and cocks on his boilers immediately after he comes on watch.

Effect of List on Boilers.—When a ship fitted with fire-tube boilers is injured in action or by accident, so that she has a *permanent* list, great care must be used to ascertain the proper working level for the altered position of the water in the boilers with reference to the highest heating surface. As stated before, double-ended fire-tube boilers have two water gages at one end and another at the other end. Single-ended boilers, placed fore-and-aft, have only two gages, both at the same end; when placed athwartship, another gage is usually fitted at the back end.

Take the case of the fire-tube boilers placed fore-and-aft and a list to port. So long as the list is small enough so that water shows in the starboard gage, no heating surface is uncovered. But if the starboard gage is empty, the port gage, which will probably be quite full, cannot be used to indicate the water level. The starboard gage must then be depended on, after the boilers have been pumped up to bring the water in sight in that gage. In the same way, with fire-tube boilers placed athwartship, the gage at the end showing the lower level must be used. In water-tube boilers, the placing of the boilers, as well as the arrangement of the drum, tubes and down-takes in relation to each other, will influence the circulation when the ship lists badly. In every case, the water level must be adjusted as well as possible to insure against the overheating of the exposed parts.

If the ship is down by the head or stern, boilers placed athwartship will show comparatively little difference in level between the two front gages. If the boilers are fore-and-aft, the matter becomes more serious, especially with double-ended boilers. As before, so long as one of the end gages, the one showing the lower level, can be depended on, the boiler may be worked with safety. But if there are front gages only, and these are full at the lowest safe working level, it will be unsafe to keep steam on the boilers.

It will be noticed that the above explanations apply only when the ship has a permanent list. The ordinary changing of water level, as the ship rolls, requires no special attention, as the heating surfaces, even when uncovered by a deep roll, remain so for a short time only and are kept damp by the splash of the water.

With water-tube boilers placed fore-and-aft, as they are generally, no trouble from the listing of the ship is likely. When placed athwartship, the circulation may be interfered with in some types having inclined tubes, if the list toward the high ends of the tubes is equal to or greater than the angle of inclination of the tubes.

Drain Cocks.—Drain cocks are placed in the lowest part of the boiler to drain all of the water out of it if desired. They are usually asbestos-packed cocks or ordinary heavy plug cocks worked by means of a socket wrench.

Air Cock.—Each boiler is fitted with a small cock at the highest point of the shell or steam drum, to permit the escape of air when filling the boiler above the level of the gage cocks, and to show, by the escape of water, that the boiler is quite full. A copper drain pipe leads down to the bilge with its end in plain view, thus giving warning when the boiler is full and keeping the surplus water away from the boiler clothing. In some water-tube boilers, as was seen in Chapter III, parts of the tubes are higher than this cock and cannot, therefore, be kept entirely full of water, as in the *Ohio* type.

Connection for Testing Water.—A small connection with a valve on it, usually an ordinary globe valve, is fitted to the cross box, or lower water drum, of water-tube boilers and to lower part of shell in fire-tube boilers for drawing water for test. In the older boilers this was connected to a *salinometer pot* in which the density of the water at a certain temperature was measured by means of a hydrometer bulb, graduated in densities at the temperature. In later boilers the salinometer pot was done away with, the end of the connection being kept free; the water was caught in a cup and the density was measured in the same way. Within the last few years the density measurements with the hydrometer have been discarded, and chemical tests are now made.

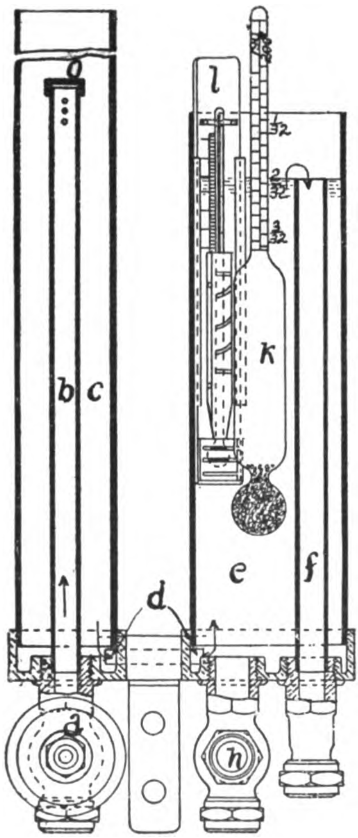


FIG. 59.

Salinometer pots are still used on evaporators, and one is shown in Fig. 59.

The instrument usual in our

navy consists of the *pot,* formed by the two cylinders *c* and *e,* and the connecting channel *d,* the *thermometer l* and the *hydrometer k.* The pot shown here may be replaced by an ordinary, deep handled pot, into which water is drawn; the one described is, however, much more convenient.

Valve *a* is connected to a small pipe leading from the water space of the evaporator, near the bottom. A cock is put in this pipe so that the evaporator can be shut off if the pipe should be broken. *h* is a drain cock for cylinder *e.* The thermometer is held in place by spring clips. The hydrometer *k* is of glass for ordinary use, there being a standard one of brass on each ship. It is a closed tube, enlarged in the middle to give buoyancy, with a lower bulb weighted with shot to make it float upright. A paper scale on the inside of the stem of the hydrometer gives the degree of concentration for three temperatures, 190°, 200° and 210°, of which the figure shows the first two. The scale is graduated to show the number of pounds and quarter pounds of salt contained in 32 pounds of the water to be tested. The average sea water is taken as containing 1/32 part of solid matter (D. K. Clark gives 1/30), and its density or concentration is represented by 1. The concentration of pure fresh water is, of course, zero, and is marked by F. W.

The principle utilized in a hydrometer is that, when a body floats freely, the weight of the body is equal to that of the liquid displaced. The weight of the hydrometer being constant, it follows that it will sink further in fresh water than in the denser sea water. By noting the line of notation on the stem for various degrees of concentration at a given temperature, the scale for that temperature is obtained. For other temperatures, the scale varies about $\frac{1}{8}$ of 1/32 for every 10° F., that is, the hydrometer will float higher in the cooler and, therefore, denser water. Hence, if the hydrometer has only one scale, which has been graduated at 200° F., and the temperature of the water in the pot is 190° when the reading of the hydrometer shows 2, the actual concentration would be $2\frac{1}{8}$, while for a temperature of 210° it would be $1\frac{7}{8}$.

When the concentration, or *saturation,* as it is often called, is to be taken, the hydrometer is removed and valve *a* is opened. The water from the evaporators is forced into tube *b,* the end of which is closed by the cap *o,* and finds its way through the small holes near the top, into the open cylinder *c,* and through *d* into *e.* Cylinder *e* is kept full to a convenient height by means of the overflow pipe *f,*

which takes off the surplus water. When the temperature of the water is falling, the hydrometer is put in, and the concentration is then read off on the scale corresponding to the temperature.

The above instrument does not measure the concentration very closely; while it is sufficiently accurate for evaporators, more delicate tests, which can be made by chemical means only, are required for boilers.

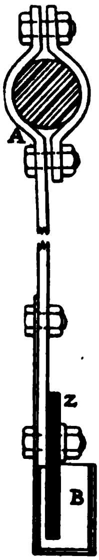


FIG. 60. Method of Securing Zincs.

The ordinary nitrate of silver test for the purity of drinking water, made by the distillers, has been in use for a long time. Nitrate of silver has a strong affinity for chlorine, and as sea water contains sodium chloride or common salt (about 2.35%), and magnesium chloride (about .31%), it will attack these and form a milky-white precipitate. The slightest trace of chloride, although this may not be sufficient to be harmful, will thus be discovered in the water. But this test, as usually made on board ship, is not a quantitative one. To show the exact number of grains of chlorine in each gallon of water, some other chemical, which the nitrate of silver will not attack until all of the chlorides have been converted into silver chlorides, must be used.

An exact method of measuring the grains of chlorine per U. S. gallon of water is described in the Appendix.

Zinc Protectors.—Until recently, zinc protectors were used in boilers in the U. S. Navy, to prevent corrosion. They are still used in the boilers of tugs and vessels of the Navy manned by crews of the auxiliary service. When used, zincs must have direct, clean metallic connection to the boiler, as shown in Fig. 60. Provision must be made for collecting the particles of zinc as it decomposes, a basket, as shown at *B* in Fig. 60, serving this purpose. The satisfactory prevention of corrosion secured by the use of boiler compound, a mixture consisting, for the most part, of sodium carbonate and of other chemicals, has made unnecessary the use of zinc protectors in boilers, where the degree of alkalinity of the water can be determined with regularity and accuracy and be maintained within a prescribed limit.

Tube Cleaning Connections.—For blowing soot off the tubes, connections are made to the auxiliary steam line and to the fire-room pneumatic line for hose connections; steam or air may be used.

Cleaning and dusting doors are placed in the boiler casing, through which an air or steam lance may be inserted between the rows of tubes or headers and the soot blown from the tubes.

Swash plates are placed in the steam drums below the water level; they are run at right angles to the axis of the drum and prevent the water from surging from one end of the drum to the other.

In some types of boilers swash plates are placed so as to direct the incoming feed water to the outer rows of tubes or to the downcomers.

Deposit pans are shallow pans placed under the internal feed pipes to catch any sediment, scale or grease that may be brought into the drum in the feed water.

CHAPTER V.

BOILER ACCESSORIES.

Boiler accessories will now be described with particular reference to those found in a marine boiler plant. They are, in general terms, as follows:

1. *Feed accessories,* those having to do with maintaining the water at the proper level in the boiler.

2. *Steam accessories,* those having to do with conveying the steam from the boiler to the steam engines and delivering it ready for use.

3. *Firing accessories,* those having to do with placing the fuel on the grate, working the fires, and removing the ashes, soot and scale.

4. *Testing accessories,* those testing outfits necessary around a properly equipped boiler, installed for measuring or testing the qualities of the steam, water and fuel.

5. *Miscellaneous accessories.*

1. The **feed accessories are**:

   Feed and filter tanks.
   Reserve feed tanks.
   Feed suction pipes.
   Feed discharge pipes.
   Valves.
   Feed pumps.
   Automatic controllers for feed pumps.
   Air chambers.
   Grease extractors.
   Feed-water heaters.
   Air extractor.
   Automatic feed regulators.

2. **Steam Piping and Accessories:**

   Main and auxiliary steam pipes.
   Expansion joints.
   Pipes passing through water-tight bulkheads.
   Separators.
   Steam traps.
   Reducing valves.
   Escape pipes.

3. **Firing Accessories:**

(a) *For Coal-and-Oil-Burning Boilers:*

Tools and appliances for handling ashes and soot.
Tube cleaners and scrapers.
Forced-draft blowers.
Dampers.*

(b) *For Coal-Burning Boilers Only* (additional to (a)).

Firing tools.
Time-firing device.

(c) *For Liquid-Fuel-Burning Boilers Only.*

Piping, tanks and pumps in general.
Duplex oil service pumps.
Hand pumps.
Pressure oil heaters.
Oil strainers.
Oil burners.
Air registers.
Meters.
Heating coils.
Automatic stop valves.
Fittings.

4. **Testing Accessories** (see Appendix).
5. **Miscellaneous Accessories:**

Whistles and sirens.
Calking tools.
Tube expanders.
Safety-valve gags.

PART I. FEED ACCESSORIES.

Feed Water.—Though generally considered as belonging to a study of marine engines, condensers and evaporator plants are properly boiler accessories. With the high steam pressures now carried in water-tube boilers, distilled or condensed water is an absolute necessity. Water obtained from on shore, while fresh and neutral, may contain scale-forming ingredients, or ingredients that break down, under high temperatures, into acids which attack the boiler materials. Scale deposited from the water on the metal of the boiler causes overheating, and consequent weakening of the metal. Acids formed eat away the metal, reducing its thickness, and hence

* Not fitted on boilers burning oil only.

its strength. The higher the steam pressure the higher the temperature. Therefore, the higher the pressure the more liable is the boiler to deteriorate and to rupture when there are impurities in the water.

While it is the practice to obtain water from on shore for filling boilers and tanks, it would be safer to use only distilled water for this purpose, as some shore waters are more injurious, both in causing corrosion and formation of scale, than sea water.

Condensers are a necessary boiler accessory, not only because they render the heat engine more efficient, but because they save for boiler feed water the steam used by the engine. Owing to the fact that only a limited supply of make-up feed water can be carried on a ship, evaporators are necessary boiler accessories, to replace the feed water lost through leakage or any other cause. As almost all boiler troubles come from using unsuitable feed water, efficient management of condenser and evaporator plants is necessary to an efficient boiler plant.

For the reasons given above, condensers and evaporators should properly be included in a treatise on boilers; as they are included, however, in the text-book on marine engines used at the Naval Academy, they will not be described here.

Feed and Filter Tanks.—After passing through the condenser the water is drawn out by the air pump and is discharged into the filter compartment of a combined feed and filter tank, located near the air pump in each engine-room. The filter compartment is separated from the feed tank proper by a horizontal plate and is divided into chambers by vertical plates, alternately secured to the compartment top and bottom. The arrangement of these plates requires the water to follow a circuitous route through the chambers and the filtering material, loofa sponges, or bags of excelsior or charcoal, or burlap.

The feed and filter tanks are connected one to the other by a cross-connecting pipe. From this pipe lead the independent suction pipes to the main feed pumps and the auxiliary feed-pump suction main, the latter supplying the several auxiliary feed pumps in the fire-rooms. Besides this pipe there are the following connections and fittings:

(a) To filter compartment:

1. Air-pump discharge pipes.
2. Vapor pipe, to atmosphere.
3. Dynamo air-pump discharge pipe.
4. Distiller fresh-water pipe.
5. Trap drains.
6. By-pass pipes from filter to feed tank.

(b) To feed tank:

1. Vapor pipe.
2. Overflow pipe.
3. Trap discharge main.
4. Drain cock.
5. Gage glass.
6. Graduated measuring scale.
7. Thermometer.
8. Zinc protectors.
9. Alkaline solution tank.
10. Clothing and lagging.

Reserve Feed Tanks.—Some double-bottom compartments are designed for this purpose. They have suction and filling pipes leading to an auxiliary feed-pump *suction* manifold. They can be filled through this manifold from a connection on the ship's side or from the distiller fresh-water main. Other leads from this manifold are to: (1) Main feed pump direct; (2) auxiliary feed-pump suction main; and (3) main condensers direct. All reserve feed tanks are connected to a *discharge* manifold of one of the auxiliary feed pumps in such a manner that they can be emptied from one to the other. They are provided with sounding tubes for measuring the amount of water contained, air escapes, and manholes for access.

Feed Suction Pipes.—The main and auxiliary feed-pump suction pipes are connected to the feed tank cross-connecting pipe, the auxiliary feed-pump pipe being in one engine-room only. Sometimes independent feed-suction pipes lead from the feed tanks to stop valves on the suction side of main feed pumps in each engine-room. The auxiliary feed-pump suction pipe connects to all the auxiliary feed pumps.

Feed Discharge Pipes.—The main feed pumps in each engine-room discharge into a pipe leading forward. This pipe discharges through or can be bypassed around the feed-water heater and grease extractor. The pipes from the engine-rooms connect in the after fire-room and form a common main leading forward to the boilers. It has branches and valves so arranged that any main feed pump can feed any one or all of the boilers. The auxiliary feed pumps discharge into an athwartship pipe having branches through which it may discharge into any boiler in its own compartment and into the main feed discharge pipe. Gate or "straight-away" valves are employed on these pipes.

Any boiler can be fed from any main or auxiliary feed pump through either its main or auxiliary feed stop and check valves.

All feed suction and discharge pipes are made of seamless drawn copper, with composition flanges brazed on. The end of the pipe is beaded into a recess in the face of the flange.

Valves in the feed suction and discharge pipes are generally gate valves, with the exception of the boiler feed stop and check valves.

A gate valve of the type made by the Nelson Valve Company is shown in Fig. 61. This valve has a bypass, as shown at *A*, in order that the pressure may be equalized on both sides of the valve and the valve be opened easily. There are many types of gate valves in use,

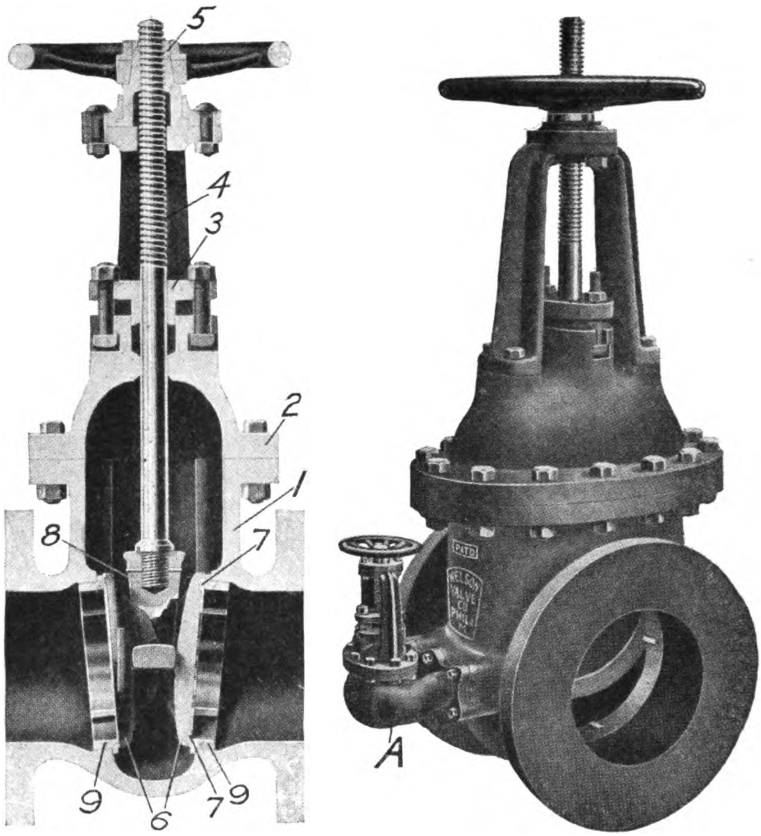


FIG. 61.—Gate Valve with Bypass.

but this one shows the principles involved. This valve consists of parts as enumerated below in tabular form:

1. Valve body.
2. Valve bonnet.
3. Valve gland.
4. Valve stem.
5. Hand wheel and nut.
6. Valve discs.
7. Valve disc, removable face.
8. Valve disc wedge.
9. Removable valve seats.

The body and bonnet 1 and 2 are made of composition, iron or steel. The other parts are of composition; 7 and 9 are made of a specially hard, close-grained composition or Monel metal. Gate valves, when wide open, cause no obstruction to the flow of the water and there is no loss of head in passing through them, except that due to friction. They are called *straight-away valves* by some makers.

Feed Pumps.—There are three types of feed pumps in general use (the classification is made entirely with regard to the water end of the pump): (1) The *piston,* (2) the *plunger* and (3) the *turbine* type.

1. **The piston pump,** shown in Plate XIII, is of the Blake vertical simplex type, and consists of parts as given in tabular form alongside of the sketch. The water end of types 1 and 2 will be described; the steam end may be the same for each.

The pump piston rod 41 is secured rigidly to the steam piston rod 40, in the cross-head 31, and enters the pump cylinder 45 through stuffing-box in upper pump head 49. The lower end of the pump rod is tapered with a shoulder at the upper end and a threaded portion at the lower end of the taper. The pump piston head 51 has a tapered hole through its central part in which the taper end of the pump rod fits. The piston head is held against the shoulder on the rod by nut 43 and lock nut 44. The piston head is made a water-tight fit in the pump cylinder liner 47 by fibrous or metallic packing rings, held in place in the piston head by the follower 52. The packing is held out against the cylinder liner by the segment ring 53 and set-out bolts 54, secured by lock pins 55. The pump piston head is slightly less in diameter than the cylinder liner. *C* is the main suction pipe connected to the two suction chambers *A* and *A′* (*A′* is not shown) through suction valves 60. The chamber *A* for the top and *A′* for the bottom of the pump cylinder are separated by a diaphragm 78. *B* is the main discharge pipe, which is connected to both suction chambers through the dis charge valve seats 61. The action of the pump is as follows: On the *down stroke* the piston creates a vacuum in the upper part of the cylinder, above the piston. The vacuum created opens the suction valves, and the pressure in the discharge line keeps the discharge valves closed. Below the piston on the *down stroke* water is being forced out through suction chamber *A′* (in rear of *A*) and through the discharge valves into discharge pipe *B*. The pressure created in

the suction chamber on top of the suction valves keeps them closed, while it opens the discharge valves as it acts underneath them. On the *up stroke* the vacuum in the bottom of the cylinder opens the suction valves in suction chamber *A'*, filling it and the bottom of the cylinder; above the piston on the *up stroke* the pressure closes the suction valves in *A* and forces the water out through the discharge valves (seats marked 61) into the discharge pipe *B*. The pump therefore discharges once each stroke, and is called a double-acting pump. The suction and discharge valves are flat-seated metallic valves with removable composition seats. They ride on the valve stems 66, which are seated at their lower ends on the suction-valve seats 61. The stems pass through the center of the discharge valves and seats and are secured at their upper ends by plugs 64, screwed into the pump body and covered with acorn nuts 65. The valves are held on their seats by the tension of light composition springs 68, secured in place around the stems by suction guards 62 and discharge guards 63. These valves are examined by removal of the valve chest cover 48. They are renewed by removing the plug and withdrawing the stem. The valves can then be removed or replaced through the opening made by the removal of the valve-chest cover. To examine or renew the pump piston packing, move piston to end of up stroke, then take off water-cylinder head and block it up against the cross-head. The follower can then be removed and the packing be examined or renewed.

All feed pumps are fitted with a water-pressure gage to show the pressure of the water in the discharge pipe, and with a water-discharge check valve in the discharge pipe near the pump. Leaky piston packing is indicated by a drop in the discharge pressure below the normal pressure for a given speed of the pump. The amount of leakage may be determined by closing the water discharge valves and running the pump at a speed that will keep the pressure the same as when the discharge valve is open and the pump is working normally. By comparing the times for a double stroke when the discharge valve is opened and closed, the percentage of leakage per double stroke can be obtained.

2. The **outside-packed-plunger pump** of the Blake type, shown in Plate XIII, Fig. 2, is what is called the *vertical simplex center-packed-plunger feed pump*. In this the pump cylinder is divided

into two parts, each part having its suction chamber and suction and discharge valves similar to the piston pump. The pump rod enters the head of the upper cylinder through a stuffing-box, and is secured to the plunger on the inside of this upper cylinder. The plunger extends into each cylinder. The openings in the lower end of the upper part and the upper end of the lower part of the cylinder are made water-tight around the plunger by the plunger packing *A, A*. Any leaks around the plunger are always visible from the outside and can be stopped either by setting up on the gland nuts or by renewing the plunger packing, either of which can be done without taking the pump apart. This pump is double-acting.

Plate XIII, Fig. 2a, shows the action of the water end of this pump when the plunger is making the *down stroke.*

3. The **turbine pump**, shown in Plate XIII, Fig. 3, is a two-stage Worthington standard turbine pump. Turbine pumps are driven by steam turbines, electric motors or high-speed steam engines. The shaft 10 is connected to the motive power at its right-hand end, passes through the pump-casing stuffing-boxes at 14 and 20, and has a thrust bearing at its other end. Two impellers 6, 6 are mounted on this shaft and are secured to it by a key. The shaft is reduced in diameter, and the right impeller fits against the shoulder, while the other impeller is held against a distance piece by a nut 28 on the shaft. The water is drawn through the suction 2 to the center of the impeller; it is thrown out by the centrifugal action of the impeller blades through the diffusion vanes 3 and 4 into the annular chamber 1. In the diffusion vanes the kinetic energy of the water in motion is converted into the potential energy of water under static head. The pressure having been increased by its passage through the first stage, the water is now led from the annular casing between the division plates 5 to the center of the second impeller, where it is again thrown out through the second set of diffusion vanes 3′ and 4′ and out through discharge 1′, and its pressure again increased. As the one shown is a two-stage pump, it will be seen that the water is discharged under pressure from the second-stage annular chamber. The pumps are made with as many stages as are necessary to give the desired pressure at the discharge from the last annular chamber; pressures have been carried as high as 900 pounds per square inch.

Automatic Control of Feed Pumps.—Feed pumps are now generally fitted with some form of automatic control that will maintain the pressure in the discharge pipe at the pressure for which the control is set.

Fig. 62 shows one form of an automatic control valve.

The steam, after passing the steam valve disc 1, acts on the under side of differential plunger 3. The valve stems 2 and 4 are screwed

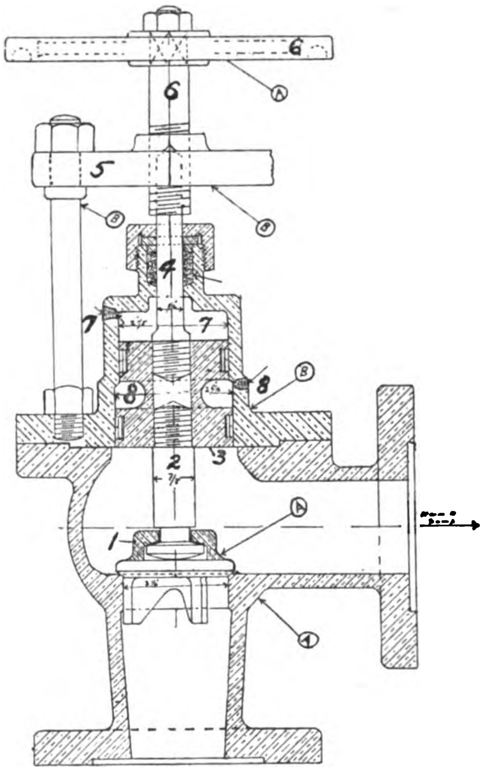


FIG. 62.—Automatic Regulating Throttle Valve for Feed Pump.

1. Steam valve disc.
2. Valve stem.
3. Differential plunger.
4. Stem of differential plunger.
5. Yoke.
6. Valve-stem sleeve and wheel.
7. Water space.
8. Leak-off space.

into 3, and any movement of 3 is transmitted to valve 1. Valve stem 4 slides in a loose fit in sleeve 6, which is turned by the hand wheel. Sleeve 6 works in a thread in yoke 5. The water space 7 is con-

nected to the discharge chamber of the water end of the pump. The areas of the top and bottom faces of 3 are so proportioned as to maintain the pressure in the feed-pump discharge greater than the pressure in the steam line by a certain ratio.

When the demand for water in the fire-room is great, as when several check valves are open at the same time, the pressure in the feed discharge line drops, relieving the pressure in 7, and the steam in the valve casing, acting on the lower face of 3, opens the valve and the pump speeds up. When the demand for feed water is light, the pressure in the feed discharge line builds up and the increased pressure, acting on the upper face of 3, closes the valve and slows the pump. The leak-off space 8 has a drain pipe to carry away any leakage from either the water space 7 or the steam space of the valve casing.

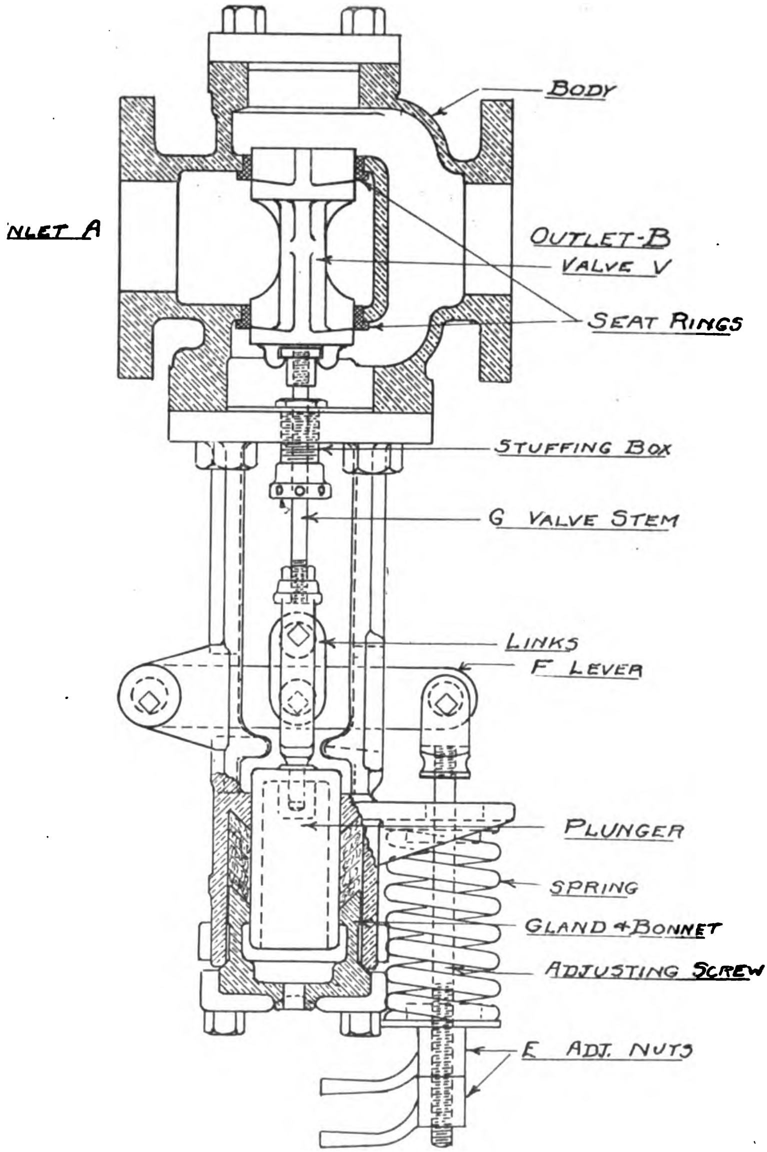


FIG. 62A.—Mason Pump Regulator.

The **Mason Pump Regulator**, Fig. 62a, is another pump regulator of good design. Its principal advantages are: accessibility of adjusting nuts, and arrangement of movement of piston valve and lever, one to two, so that the spring resistance required is only one-half that of a direct spring on the valve stem. This enables a more resilient spring to be employed which results in a more sensitive action. The plunger is packed with Queen's packing, a patented article, formed to shape, and of special material to resist oil. This packing is self-setting. The operation of the regulator is as follows: Steam enters at *A*, passes around the balanced valve *V* and leaves at *B*. The pump discharge is connected through a pipe to the bottom of the plunger cylinder. As pressure builds up in the pump discharge line the plunger lifts against lever *F*, overcomes compression of spring, and through valve stem *G* closes valve *V*. As pressure in discharge line falls, compression of spring pulls down lever opening valve *V*. The compression of the spring is regulated by the adjusting nuts *E*.

Air Chambers.—Feed pumps should have vacuum chambers on the suction line, as they provide a uniform flow of water to the pump and make it run smoothly.

Air chambers on the discharge line tend to cause a steady flow of water and to reduce the pounding of the pump at high speeds, by the cushioning effect of the air contained in them. The air chambers on the discharge side should have from 2 to 3½ times the volume of the piston or plunger displacement. The vacuum chambers should be from 1 to 1½ times the piston displacement, and should be placed so as to receive the impact of the column of water in the suction pipe.

Feed pumps are fitted with a connection from the discharge to the suction chamber in which a spring-loaded relief valve is installed, so that in case all feed check valves in the fire-rooms are closed at once and the automatic control valve fails to operate, the excess pressure will open the relief valve and bypass the water to the suction side. The automatic control valve is generally designed to maintain a pressure in the feed discharge line at least 50 pounds greater than boiler pressure; the relief valves are set to relieve at about 100 pounds greater than boiler pressure.

Grease Extractor.—The feed suction line from the feed tanks to the main feed pumps is sometimes fitted with a *grease extractor*.

The grease extractor used in the navy is composed of a casing and a perforated cartridge covered with linen or toweling and filled with loofa sponges. The water enters the casing and finds its way through the filtering material, then passes through the cartridge to the main feed suction pipe.. This extractor should be installed double, so that one can be in use while the other is being cleaned. Where there is much grease in the feed water, the extractor, where installed singly, can be bypassed while it is being cleaned.

Feed-Water Heaters.—Where feed-water heaters are installed in the feed suction lines, they are called *low-pressure heaters;* when these are used, an additional pump is required to pump the water from the feed tank through the grease extractor and feed heater (either or both of which can be bypassed) into the feed suction lines. The pressure generally carried in low-pressure heaters is not over 20 pounds on the water side; and the temperature of the feed is limited to the highest that the feed pump will lift. With heaters of this type, the temperature can never be carried over 200° F., and with the average feed pump about 180° F. is the limit. The limiting temperature of the water which the feed pump will lift is due to the reduction in pressure on the suction stroke which must take place in order that the pump may lift the hot water. When the pressure is reduced a certain amount, the water will boil and the pump will lift steam instead of water.

Feed heaters in the feed discharge lines are called *high-pressure heaters;* their heads and tubes are tested to 550 pounds and their shells to 75 pounds pressure. The water in both the high- and low-pressure types passes through the tubes and exhaust steam surrounds them.

When using exhaust steam to heat feed water, it has been found, both by theoretical calculations and by practical tests, that for every 10° F. rise in temperature of feed water there is a 1% reduction in the amount of heat necessary to produce the steam, with a corresponding reduction in fuel used.

The temperature of the feed water leaving a high-pressure heater should be within 10° of the temperature of the exhaust steam. The navy requirements are that the exhaust steam should not be over 10 pounds per gage or 25 pounds absolute. The temperature of steam at this pressure is 240° F., and the temperature of the feed can be carried to within 2° F. of the steam. A vessel having a high-pressure heater should be from 3½% to 4% more efficient than a sister

vessel having a low-pressure heater and steaming in the same squadron. The feed-water heaters used in the navy are: (1) The *straight flow,* (2) the *U-tube,* (3) the *coil* and (4) the *film.*

The **straight-flow heaters** are very similar to a condenser, and consist of a cylindrical shell filled with tubes. The tubes are expanded into the tube sheets. The shell has a water head at each end, one of which is divided. The feed water enters one chamber of this head, goes through a part of the tubes to the other head, then back through the other part of the tubes to the second chamber of the head to the discharge line. The exhaust steam surrounds the tubes in the shell; one tube sheet is connected to the shell by a method which allows for the expansion of the tubes.

Tube Retarders.—Recently there has come into use with straight-flow heaters a device known as the *tube retarder.* This device is a flat strip of brass twisted into spiral loops at regular intervals along its length, inserted in the tube and firmly secured at one end. The retarder extends the entire length of the tube and agitates and checks the flow of the water. The retarders increase the efficiency slightly, by increasing the agitation of the water and breaking up the water film inside the tubes.

In the **U-tube heater**, shown in Fig. 63, designed by the Bureau of Steam Engineering, the tubes *D* are bent into U-shape and expanded into the tube sheet *C*. The feed water enters through the opening *E*, and passes through the tubes, and out to the feed discharge line through the opening *F*. Exhaust steam enters the casing *A* at *H* and leaves through *G* on the under side of the casing. If this heater is placed with the tubes in the vertical plane, the exhaust

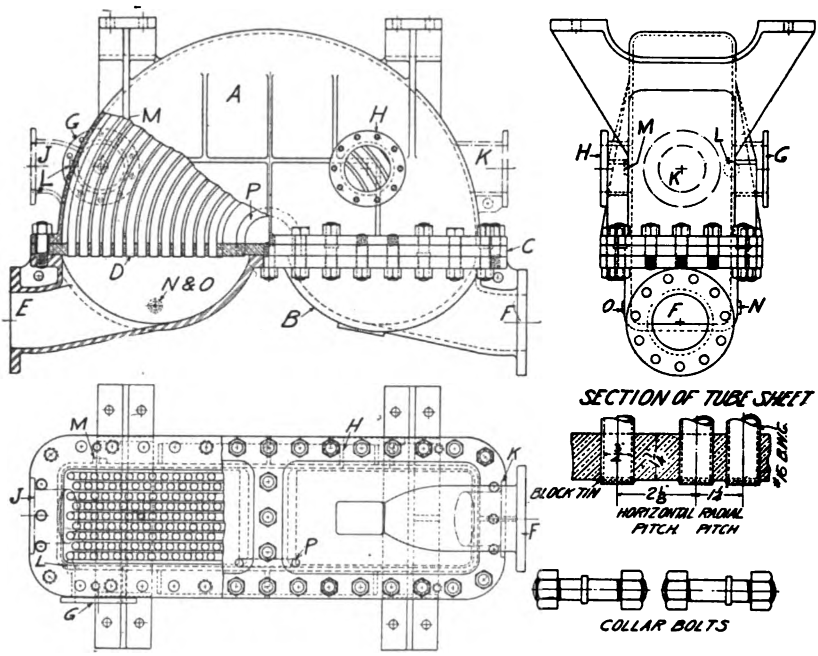


Fig. 63.

steam enters at an opening *K* (top) and is drained out at *J* (bottom).

In **coil heaters** the water is forced into manifolds placed near the bottom of the shell, then through copper coils to a manifold near the top of the shell, then out to the feed line. The coils are secured to the manifolds in different ways, generally with cone or screwed joints, or ground-joint unions.

The **Schutte-Koerting Film Heater**, shown in Plate XIV, is of the type installed in the U. S. Navy. The circulation of the water and steam is as shown. The water enters first into the lower half

of the main header *A*, passes into the outer copper tube and around the inner copper tube, and then enters header *B*. From header *B* it flows back through the outer tubes and around the inner tubes in the upper half of the heater to the upper half of header *A*, and thence to the feed line. The diaphragm *D*, separating the header into two compartments, is corrugated to give stiffness and to allow for expansion. The tubes, two sets of which are shown and the others of which are indicated by the center-lines, are spirally corrugated for increased strength and heating surface. The corrugations are spiral, to give increased agitation to the water as it passes through the heater. It has been found that the passage between the inner and outer tube must be at least $\frac{3}{16}''$, in order that the tubes may not foul each other on account of unequal or irregular expansion. The inner tubes are .083″ and the outer tubes .096″ thick. The details of the joints of the tubes and headers are shown at *O*, *K* and *M*. A number of stay-bolts, *S*, support the flat parts of the headers. A number of feet not shown project from the periphery of *B* and keep it centered in the shell. It will be seen that the header *B* is free to move back and forth when the tubes expand and contract.

Plate XV shows the **Reilly Multicoil Feed Heater** as installed on the U. S. S. *Nevada*. The shell, *S*, is of steel plate. Water enters the lower manifold *M*, from which it passes through a number (in this case 52) of copper coils *K* to the upper manifold, and thence to the feed discharge line. The manifold is shown in *A* and *B*. The particular advantage of this heater lies in the absence of gaskets, which, in the U-tube and straight-flow types, make it very difficult to keep the joints of the heads tight. The method of securing the coils to the manifolds is shown at *D* and *E*.

The end of coil *K* is turned into a mushroom as shown, and is held tight against the ferrule *F* by the coil nut *N*, which fits over end *a* of the projection on the manifold *M*.

Air Extractors.—On the latest ships in the U. S. Navy, *air extractors,* Fig. 65, are installed in the highest parts of the feed discharge lines near the boilers. Air collects in the air chamber of the extractor and is blown off through the blow-off pipe. The action of the extractor is similar to that of radiators in the highest parts of steam and hot-water heating systems of buildings. Air collects in these high radiators from the system below, and must be blown off through a pet-cock before the radiator will become hot. This example also illustrates the low heat conductivity of air. It is

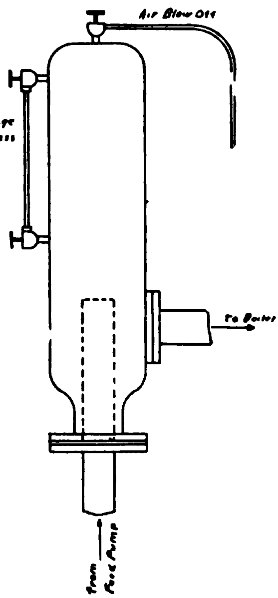


FIG. 65.—Air Extractor.

desirable to remove as much air as possible from the water before it enters the boilers, because the oxygen in the air is the most potent factor in the corrosion of the boiler metal.

Automatic Feed Regulators.—Automatic feed regulators are used extensively in some foreign navies and in the merchant marine. The principle employed is that of stopping the feed into the boiler when the water has reached a certain level in the drum. The contrivance for regulating the water supply to the boiler is fitted in the steam drum. While the automatic feed water regulator has been used to a limited extent in the U. S. Navy, its reliability has always been questioned and it is not now installed.

PART II. STEAM PIPING AND ACCESSORIES.

The feed water has been traced from the condenser to the boiler. The steam will now be followed from the boiler stop valves to the place where it is to be used.

The general plan is to have two systems of main steam piping symmetrically placed on each side of the ship. On water-tube boilers there is only one steam stop valve. In some cases the *main steam line* is connected to the boiler through the *auxiliary steam line,* and in others the auxiliary steam line is taken from the main line, the main line being directly connected to the boiler stop valve.

On the latest vessels, when superheaters are fitted, the boilers are directly connected to the main steam lines, the connection being so arranged that the steam can be either sent through the superheater or bypassed to the main line. The branches from the main steam line to the boilers are all of the same diameter; the main steam line increases in diameter from the forward boilers aft, at each successive connection. Stop valves, called *cut-out valves,* are placed in the main steam line at intervals in such a way that sections of boilers, or sections of the main steam line, can be cut out as may be necessary. Just forward of the main engine throttle valves the main engine stop valves are placed. Main steam line stop valves are geared so that they may be operated from the deck above.

The stop valves in the main and auxiliary steam lines are screw-down globe valves with flat valve seats. A bypass controlled by a small valve connects the steam spaces on each side of the larger valve. In the forward part of the engine-rooms the steam lines are connected to each other by an athwartship connecting pipe, having a stop valve at each end. The forward ends of the main steam pipes are connected by a loop of pipe that runs across the ship in the forward fire-rooms. This loop forms the forward part of the auxiliary steam line; branch pipes run from it to the various machines forward. In the same manner a loop connects the after ends of the port and starboard main steam lines, crossing in the after part of the engine-rooms. These loops forward and aft take the place of the auxiliary steam line and branches lead from the loops to the various machines forward and aft. Each main steam line has a pipe, called a "bleeder," leading to the condenser. This

pipe removes live steam from the lines when it is desirable to care for surplus steam which otherwise would escape by the boiler safety valves.

In each fire-room the port and starboard main steam lines are connected by athwartship pipes which have valves at each end near the main steam pipe. In the latest ships the evaporator steam supply is generally taken from the main steam line in one of the fire-rooms. Main steam lines are given a slope toward the boilers or toward the separators so the condensed water will run to one of these. Low places in all steam lines or valves, where water can collect, are drained to automatic traps.

All steam pipes 2″ in diameter and above, and all pipes that carry superheated steam are made of seamless-drawn steel. Pipes, less than 2″ in diameter, not subjected to superheated steam, are made of copper. All exhaust piping is made of copper, that of 10-inch diameter and less being seamless drawn. All flanges for steel pipes are of forged steel; the pipes are expanded into the flanges and the end of the pipe is beaded over to fit a recess and be flush with the face of the flange. Flanges on superheated steam pipes are plain-faced, and the joints between these flanges are made up with a thin wash of boiled linseed oil. All steam pipe flanges are faced and grooved, and the joints are made with case-hardened corrugated copper gaskets. Exhaust steam pipe joints are made with fiber gaskets.

Expansion joints are placed in steam piping, main and auxiliary, wherever there are not bends in the piping sufficient to allow for the expansion. The pipes are rigidly secured to the ship's structure at certain intervals, and are said to be *anchored* at these points. Wherever the pipe runs straight between two successive anchorages, expansion joints are placed. The rigid part of the expansion joint is generally anchored at or near the after bulkhead of each compartment, the pipes passing through stuffing-boxes in the bulkheads. In small pipes U-bends are placed to take up the expansion; they are placed near the center of the compartment, and the pipe is anchored at each bulkhead. The weight of the pipes is carried by supports through which the pipe can expand. These supports are sometimes riveted to bulkheads and sometimes swing from the beams overhead.

Fig. 66 shows an expansion joint as generally fitted in naval vessels.

A is the stuffing-box casting, generally anchored to the ship's structure; *F* is the gland, with its studs screwed into flange *X* and nuts outside of the gland by which the packing in *S* is adjusted and by which the joint around the sliding pipe *P* is made steam-tight. One end of the steam pipe *C* is shown with its flange *Z* bolted to the flange *Y* on *P;* the other end of the main is similarly flanged and bolted to the flange *K* at the opposite end of *A*. To prevent the sliding pipe *P* from drawing out of *A*, **T**-headed stop bolts *B* are fitted between flanges *X* and *Y*. Bolts *B* slide through holes in flange *X* with a loose fit, the **T**-head being placed on the right side of flange *X*.

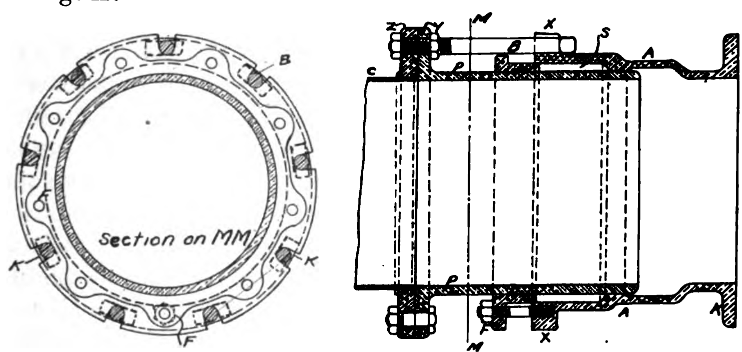


FIG. 66.

In some expansion joints there are nuts on both sides of the flange *X;* the one on the right side is adjusted to be just clear of the face of *X* with the pipe cold, and that on the left of *X* to be just clear of *X* with the maximum steam pressure in *C;* the nuts at flanges *Y* and *Z* are set up hard against faces of flanges.

Expansion joints exposed to superheated steam are made of cast steel, those not exposed to superheated steam are made of either cast steel or composition. The glands are made of composition. Expansion joints are fitted to all steam, exhaust and feed piping where there are not ample bends to provide for the expansion. Where there are ample bends and no expansion joints are fitted, the pipes are so fitted as to put them under tension when cold.

Pipes Passing through Water-tight Bulkheads.—Steam, exhaust and feed piping are passed through water-tight bulkheads in one of the following three ways:

1. When the pipe is anchored to the bulkhead, the flange on one section of the pipe is about one and one-quarter times the diameter of the standard flange for that size of pipe, and has two rows of bolt holes in it. This flange is bolted to the bulkheads through the outer row, and to the standard flange of the other section through the inner row of bolt holes.

2. When the pipe is not anchored to the bulkhead, but has a sliding motion through it, the joint in the bulkhead is made tight with a stuffing-box.

3. When the bulkhead is adjacent to or part of a magazine, to prevent the heat from being conducted from pipe to bulkhead a casting with an annular chamber in it is fitted to the bulkhead around the pipe. Water circulation is kept up in the annular chamber by a pump.

Separators.—To remove water from steam pipes, all pockets and places in pipes or valves where water can collect are connected by drain pipes to automatic traps. As an additional precaution, where the motive power is a high-speed reciprocating engine or turbine, separators are fitted in the steam lines in the engine-rooms near the throttle or controlling valves.

The function of the separator is to collect such water as is not taken care of by the traps and drains, and run the water so collected directly to the feed tanks, thereby avoiding the danger in allowing water to go through a high-speed reciprocating engine or turbine. The separation of water and steam is effected in one class of separator by making an abrupt change in the direction of the steam and water. In another class there is, in addition, a centrifugal action, by means of which the water is thrown to the bottom of the separator and drained off, the steam rising to the controlling valve.

An excellent separator can be made as follows: Take a short section of pipe of large diameter; cap the bottom end; connect a drain valve to the capped end; fit a gage glass on the side of the pipe near the bottom; cap the top end, and through this cap secure the outlet end of the steam pipe; let it extend down vertically from the cap on the inside of the pipe a distance of about four times its diameter; from the side, near the top and well above the end of the outlet steam pipe, secure the steam inlet pipe. The entering steam current is then changed quickly, first through 90°, then through 180° and the entrained water is thrown to the bottom of the pipe, where, if connected to a trap, it is discharged to the feed tanks, or,

if not, it is drained to the bilge by opening the drain valve when the gage glass shows water in the separator.

The Stratton centrifugal separator is shown in Fig. 67. The wet steam enters at the right of the figure and passes around the central pipe in a spiral direction, as shown, the heavier particles of water being thrown, by centrifugal action, against the sides of the casing. The water runs down into the reservoir below, and the dry steam, after reaching the bottom of the central pipe, passes into it and out of the separator by the upper opening at the left, and thence to the engines. The reservoir is fitted with the usual automatic gage glass and a drain pipe at the bottom.

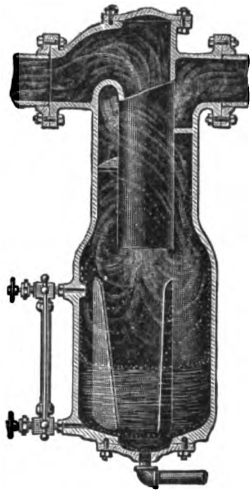


FIG. 67.

It was found in practice that, when steam of high pressure was used, the rotary motion imparted to the water as it separated was continued, in some cases, especially where the separator was short, down to the bottom of the reservoir. This resulted in a layer of water against the sides of the reservoir, and a space filled with steam in the center. The gage glass would show full and, on opening the drain, steam would be blown out. To remedy this defect, by breaking up the whirling motion of the water, wings or plates are put in the reservoir, as shown, standing at an acute angle to the course of the current. These cause the water to settle solidly towards the bottom, and the gage glass will give the correct height at all times.

If the traps on lines from separator to feed tank get out of order, they should be bypassed with valves adjusted so that water always shows in the bottom of the separator gage glass. If this is not done, much live steam may be wasted by blowing it through the traps to the feed tanks.

All drains from steam lines and separators lead to automatic traps; the traps are fitted so that they can be bypassed. Traps are fitted to discharge into the feed tanks or condensers in order that all fresh water possible may be saved for use in the boilers. The bypass is made either by connecting the inlet steam to the discharge from the trap by pipe connections outside of the trap, or by connecting the same internal passages in the trap and fitting a valve by which the trap can be shut off and bypassed.

Steam Traps.—There are three classes of automatic traps:

1. *Intermittent flow* or *bucket traps.*
2. *Differential traps.*
3. *Expansion traps.*

Intermittent Traps.—Figs. 68 and 68a show the Lytton bucket trap, which is of the intermittent-flow type.

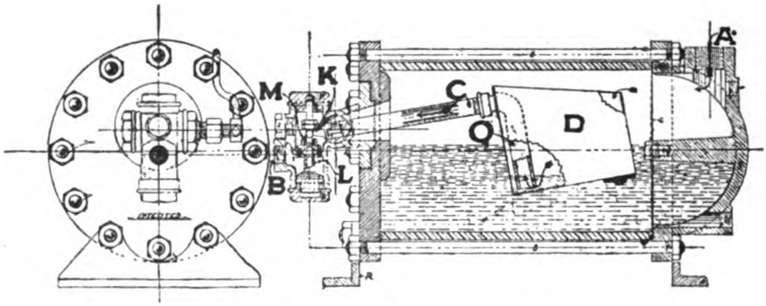


FIG. 68.—Lytton Bucket Trap.

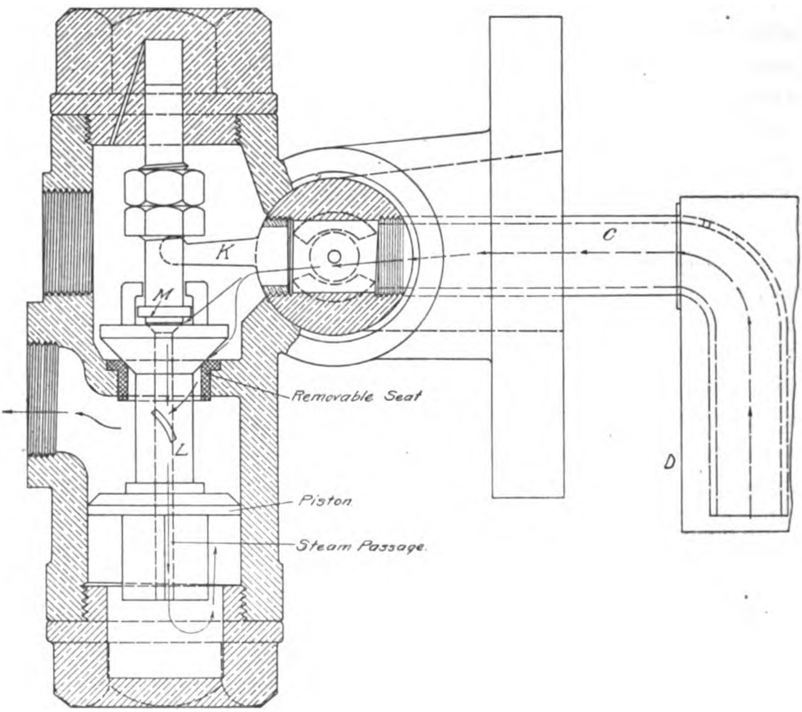


FIG. 68a.—Details of Main and Auxiliary Valves.

It consists of a chamber, a bucket, a main and an auxiliary valve. Discharge pipes lead to and from the chamber and valve chest respectively. Water and steam flow through the inlet opening *A* to the chamber and raise the bucket *D* until it strikes the top of the chamber; when the water rises to the top of *D*, it overflows into it; the bucket *D* then fills and drops to the bottom of the chamber; this causes an upward movement of the lever *K*, which raises the auxiliary valve *M* and admits the pressure in the trap to the under side of the piston attached to the main valve *L*. This pressure opens the main valve and the water is forced out of the trap through bucket *D*, connection *Q* to pipe *C*, and thence to outlet *B*. The water flows from the trap chamber until level with the top of *D*, when it is at its lowest position; then that in *D* is blown out until *D* floats (in the position shown) and closes the valves *L* and *M*. *L* and *M* remain closed until *D* fills and drops again. All parts of this trap, except the float, are outside of the chamber, and are accessible. All of the automatic functions of the trap can be performed by hand from the outside by means of the lever shown in the end view.

The bucket or intermittent-flow trap is the one in most extensive use in the U. S. Navy.

Kiely Steam Trap.—Fig. 69 shows the Kiely and Mueller steam trap..

Water enters the inlet, flows over the deflecting shield *D*, and then down under and up around the bucket *B*. When the water reaches the top of *B*, it flows over its edge into *B* and causes *B* to sink. *B*

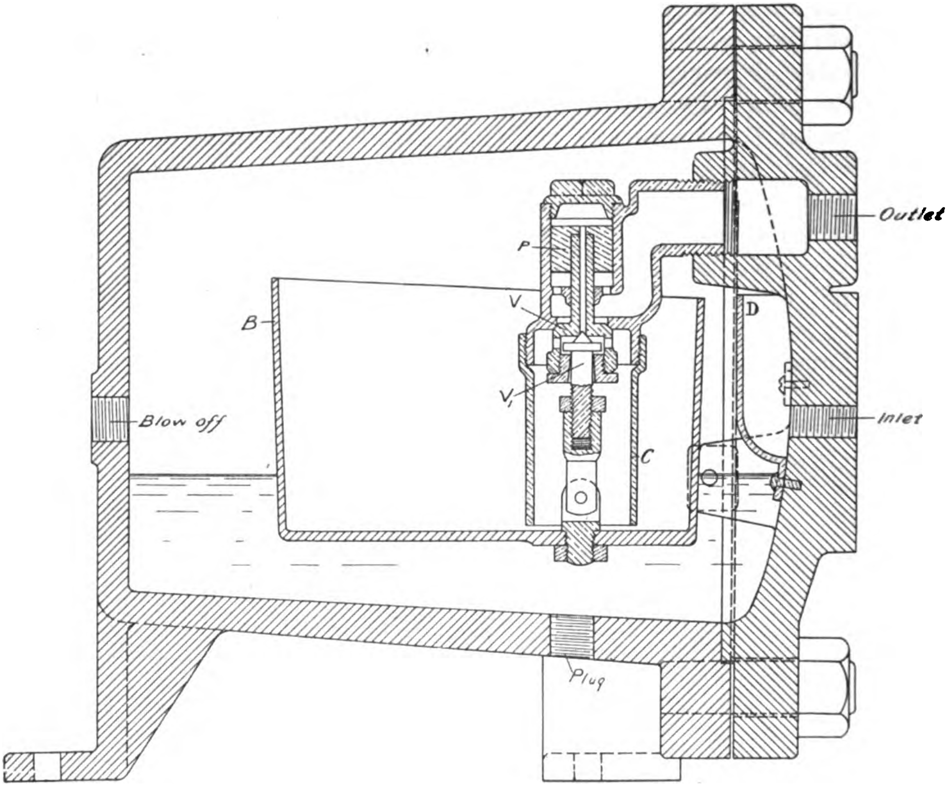


FIG. 69.—Kiely and Mueller Steam Trap.

is pivoted at *O* as shown, and, when it sinks, it pulls the auxiliary valve V_1 down and admits water to the upper end of the piston *P*.

The pressure on top of *P* permits the main valve *V*, to which *P* is secured, to open, and the water in the bucket rushes up through the casing *C* and out through the outlet to the drain pipe. When all the water is blown out, the water outside the bucket lifts the bucket and closes both valves.

Sometimes a rod is fitted through the top of the trap so that it may be screwed down into the bucket to dump the bucket by hand.

Expansion Traps.—Expansion traps are used very little in the United States Navy. The principle of the expansion trap is that of the control of the discharge of water from the trap by means of the control of a valve which is opened and closed by the expansion and contraction of metallic parts caused by their change in temperature due to alternate contact with steam and water.

Reducing Valves.—The steam pressures carried in the boilers and main and auxiliary steam pipes are higher than are necessary for many auxiliary engines found on board naval vessels, and are too high for many of the purposes for which steam is used. These pressures are reduced either by throttling the steam by use of the throttle or control valve, or by interposing a reducing valve in the branch from the main or auxiliary steam lines between the line and the machine for which the steam is needed.

As there are generally many different pressures required for the various machines connected to the auxiliary steam line, the throttling method will not answer; so the method of using reducing valves placed in the branches from the auxiliary line is resorted to.

By means of the reducing valve the steam pressure on the low-pressure side of the valve is automatically kept constant at the pressure for which the valve is set, as long as the pressure on the high-pressure side of the valve is greater than that on the low-pressure side.

The following three reducing valves are used extensively in the U. S. Navy.

The Lytton Reducing Valve.—Fig. 70 shows the Lytton Reducing Valve. The parts of this valve are as follows:

1. Fixed top of spring 3.
2. Adjusting nut.

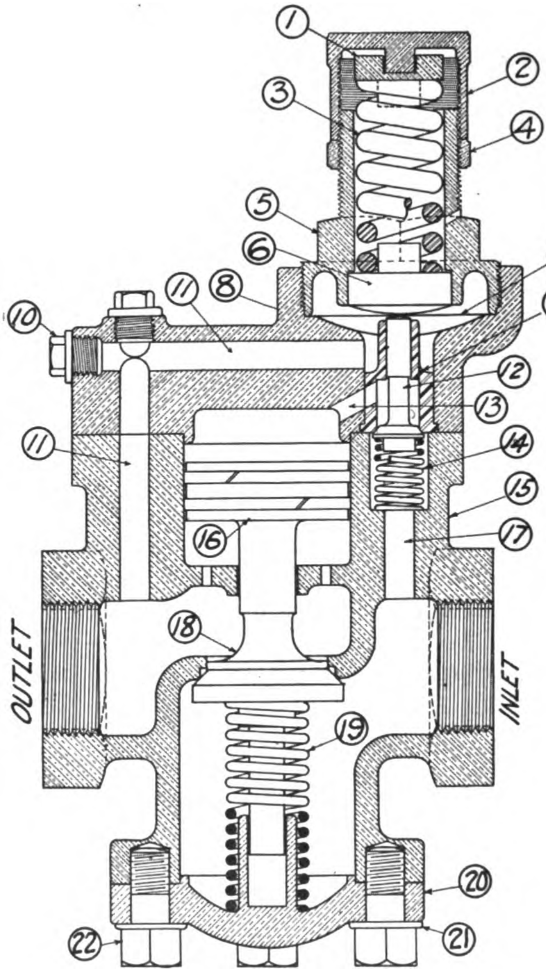


FIG. 70.—Lytton Reducing Valve.

3. Adjusting spring.
4. Lock nut for adjusting nut.
5. Hexagon on adjusting-spring casing.
6. Base of spring 3.

7. Diaphragm.
8. Valve bonnet.
9. Guide for pilot-valve piston.
10. Plugs for cleaning or examining passage 11.
11. Steam passage for reduced steam to chamber under diaphragm 7.
12. Pilot valve.
13. Steam passage from top of piston 16 to top of pilot valve.
14. Pilot-valve spring.
15. Valve casing.
16. Piston to main valve 18.
17. Steam passage from inlet steam to under side of pilot valve.
18. Main valve.
19. Main-valve spring.
20. Lower bonnet to valve chamber.

21 and 22. Studs and washers to lower bonnet.

The pilot valve 12 is kept open by the adjusting spring 3, pressing against the diaphragm 7, which transfers this pressure to the stem of the pilot valve 12. Steam enters the valve chamber through the inlet, rises through steam passage 17, and passes through the pilot valve and through the passage 13 to the top of piston 16. Owing to the large area of 16, the main valve 18 is opened against spring 19 and against the inlet pressure.

Steam now passes through the main valve to the outlet, the pressure being reduced by the throttling action of the main valve. Steam in the outlet chamber has access through passage 11 to the under side of diaphragm 7.

The valve is set by the action of the adjusting nut 2 on the adjusting spring 3. As the pressure in the outlet chamber rises above that for which the valve is set, it tends to raise the diaphragm and allows the pilot valve 12 to close part way. This reduces the pressure on top of 16, enabling the inlet pressure and spring 19 to partly close the main valve and reduce the outlet pressure. If the outlet pressure is too low, diaphragm 7 is forced lower by 3; this causes a higher pressure on top of 16 and a consequent greater opening of the main valve.

The Foster Pressure Regulator.—The Foster Pressure Regulator, described in Barton and Stickney's Naval Reciprocating Engines and Auxiliary Machinery, is shown in Fig. 71.

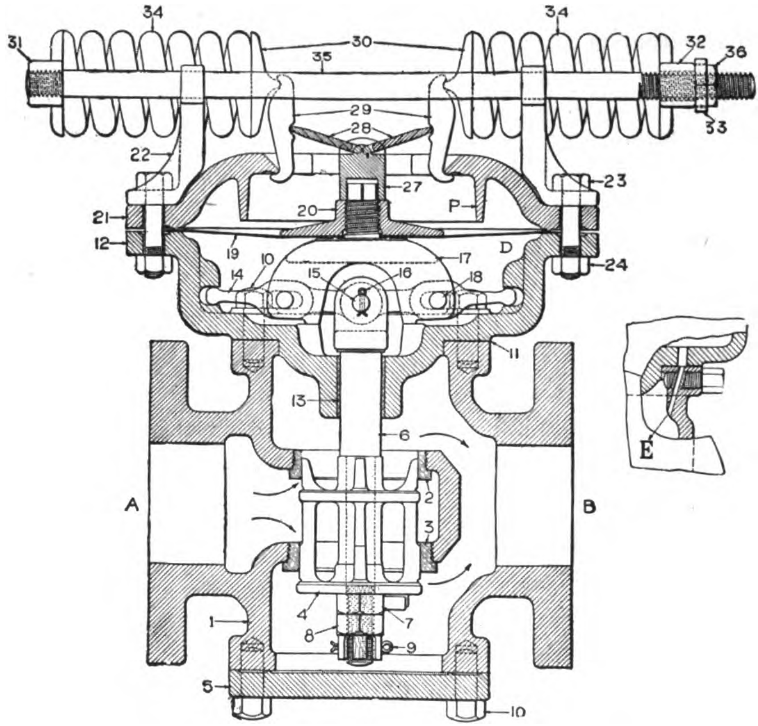


FIG. 71.—Foster Pressure Regulator—Class "W."

No.	*Name of Part.*
1	Body.
2	Upper valve-seat.
3	Lower valve-seat.
4	Maine valve (or clapper).
5	Bottom flange (or plug).
6	Valve (or clapper) stem.
7	Valve-stem nut.
8	Valve-stem jamb-nut.
9	Valve-stem jamb-nut cotter-pin.
10	Bottom and top flange screws.
11	Gasket.
12	Top.
13	Top liner.
14	Valve-stem levers.
15	Valve-stem pin.
16	Cotter-pin for 15.
17	Diaphragm center.
18	Diaphragm center pin.
19	Diaphragm (set—consisting of one or more).
20	Diaphragm jamb-nut.
21	Hood.
22	Spring-bolt bracket.
23	Spring-bolt bracket bolts.
24	Spring-bolt bracket and hood-bolt nuts.
25	Hood bolts.
26	Port screw.
27	Toggle-lever base.
28	Toggle lever.
29	Toggle-lever links.
30	Pivot washer.
31	Plain yoke.
32	Lock yoke.
33	Lock-yoke wrench.
34	Springs (two to a set)
35	Spring bolts.
36	Spring-bolt nuts.
37	Diaphragm chamber plug.

The principle of its action is that of wire-drawing the steam by throttling or restricting the opening at the main valve through which the steam passes from entrance to delivery. The steam enters

valve at *A*, Fig. 71, and, flowing in the direction indicated by the arrows, passes out at *B*. In its course it enters chamber *D*, through port *E*, closing valve 4 against the opposing power of the springs 34. Any increased pressure on the diaphragms overcomes the resistance of the springs, lifting valve 4 toward its seats. Should the delivery or reduced pressure decrease, the springs overcome the pressure on the diaphragms and force valve 4 open. An equilibrium is thus instantly established. The desired delivery pressure is controlled by adjusting nuts 36—turning to the right increases, and turning to the left decreases, the delivery pressure.

Leslie Reducing Valve.—Fig. 72, taken from Barton and Stickney's Naval Reciprocating Engines and Auxiliary Machinery, shows a sectional view of the Leslie valve, which consists of a main body *A*, containing the main valve *D*, main-valve spring *E*, piston *F*, diaphragm *G*, controlling valve *J*, with its spring *K*, the adjusting spring *L*, adjusting cap *O*, steam inlet *R*, steam outlet *T*, inlet port *S* to controlling valve, and port *U* to diaphragm chamber.

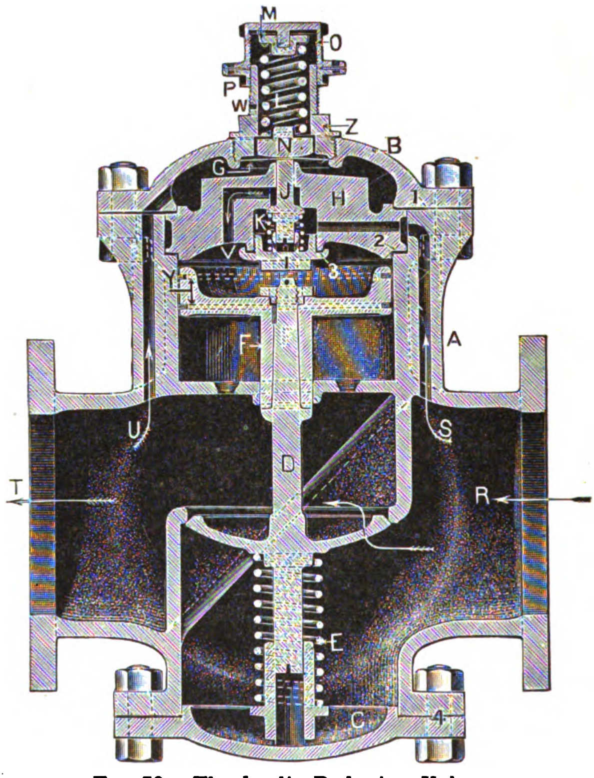


FIG. 72.—The Leslie Reducing Valve.

The action of the Leslie valve is as follows: Steam enters at *R* under boiler pressure and leaves at *T* under the reduced pressure. The figure shows the main valve closed, as it is when no steam is on *R*. Main valve *D* is held against its seat by the spring *E*. Attached to the upper end of its stem is the piston *F*, which works in a cylinder, the top end of which is always in communication with *R* when the controlling valve *J* opens. This valve is held against its seat by

the small spring K, and its stem is independent of the small diaphragm G. The under side of G is always in communication with outlet T, and its upper side is subject to the tension of the adjusting spring L acting on the block or seat N.

When the valve is to be regulated after being secured in place, the cap O is unscrewed until there is no tension on spring L. The drain cocks on the delivery side and at the bottom of the lower bonnet C (not shown) must be opened, and then the bypass valves be opened if fitted, or the stop valve on the inlet side be opened very slowly until it is opened full. The cap O is now screwed down slowly, a little at a time, to allow the regulator to become thoroughly heated and drained. When the desired pressure on the delivery side has been obtained (the drains being closed when all water has been blown out and the delivery pressure is steady), the lock nut P is set up tight against O, and the two are locked together.

When the cap O is screwed down, it puts L under tension. The latter forces G down and partially opens valve J against the spring K and the pressure of the inlet steam, which has been admitted to the back of J through the port S. The steam reaches the top of F through the port V and forces the piston and the main valve D down and partially open. Steam is now wire-drawn from R into T and, at the reduced pressure, acts on the bottom of diaphragm G, through the port U, against the tension of the spring L, and acts also on the under side of the piston F, through a number of holes in the bottom of the cylinder. So long as the pressure in T, and therefore that under the diaphragm, balances the tension of the spring L, there will be no change in the position of J as fixed by the setting of spring L, and hence no change in F and D. But if the delivery pressure falls, spring L acts downwards and opens J wider, which results in a greater pressure on top of F and a correspondingly greater opening of D, and therefore in a greater pressure in T until equilibrium is again restored between the two sides of the diaphragm. The action is similar, only in a reversed manner, when the pressure in T rises.

These valves are of the same construction for all sizes from $\frac{1}{2}''$ to $20''$, except that all valves larger than $4''$ must be fitted with bypass valves so that the pressure on the delivery side can be raised before the stop valve on the inlet side is fully opened, in order to prevent pounding or other injury. The size of the diaphragm does not change with each size of the valve, there being only two sizes

used, one for valves from ½″ to 1½″, and the other for valves 2″ and larger. This is made possible because the movement of the diaphragm affects only a smaller controlling valve *J*, and not the main valve *D* directly.

Escape Pipes.—There is abaft each smoke pipe a copper escape pipe open at the upper end to the atmosphere and extending from near the top of the smoke pipe to the boiler compartments.

In the boiler compartments branch pipes connect the safety-valve chambers to the lower ends of the escape pipes; in one of the boiler compartments the branch pipe also connects with the auxiliary exhaust line. By this arrangement the escape pipe will take care of the escaping steam when the safety valves pop and the auxiliary exhaust can be turned into the atmosphere. A drain is run from the safety-valve chamber to the bilge.

PART III. FIRING ACCESSORIES.

The discussion of subdivision (a) (Firing Accessories for Coal-and-Oil-Burning Boilers) is postponed until after the discussion of subdivisions (b) and (c).

(b) Firing Accessories for Coal-Burning Boilers.

Firing Tools.—The fireman's tools are *shovels,* short and long *hoes, prickers,* short and long *slice bars,* and *devil's claws.* The first two need no explanation, except that the hoes are moderately heavy for cleaning fires and lighter for hauling ashes.

Prickers are round bars with one end flattened and turned up at right angles, the bent-up end often having a stop welded on to prevent the flat end from entering the fire too far. The length of the flat end, or the position of the stop on it, will depend on the thickness of fire best suited to the coal used.

Slice bars are round bars with one end flattened, and a more or less rounded point, so that they can be slipped easily between the grate and the fire.

The *devil's claw* is something like an ordinary rake with five or six heavy prongs. It is not much used, most firemen preferring the hoe.

All of these tools have an elliptical ring turned at the handle end, as straight ends are much harder to handle.

To lighten the work while using long hoes in cleaning fires or in hauling ashes, a removable cross-bar, called a *lazy bar,* is placed in supports fitted to the furnace door frame and to the ash pit.

Coal buckets are round, cylindrical iron buckets with heavy reinforced bottoms. They have two hand grips riveted to opposite sides about 8″ from the tops. They hold about 100 pounds of the average coal. Hooks are also supplied to catch the grips and hook into an eye on the trolley on the bunker trolley rails.

Time-Firing Device.—The *time-firing device* is a contrivance for making at definite intervals of time a signal by which the fireman coals the furnace or works the fire. It insures uniform and regular firing of all boilers. The time interval of the signal is varied to suit different rates of combustion at different speeds. The signal is an electrically operated bell and light on the bulkhead in easy view.

(c) Firing Accessories for Liquid-Fuel-Burning Boilers.

The requisite installation for burning fuel oil includes:

1. *Fuel-Oil Piping.*—Steel piping connecting parts of the fuel-oil-burning system.

2. *Fuel-Oil Storage Tanks.*—These are specially constructed compartments in which the fuel oil is stored. They correspond to coal bunkers in a coal-burning ship.

3. *Booster Pumps.*—Pumps used to take oil from or discharge it into the storage tanks, to take it from or discharge it to a vessel alongside, and to pump it into the fuel-oil service pump suction.

4. *Oil Service Pumps.*—Pumps used primarily to discharge the oil through the oil heaters to the burners. They are heavier pumps than the booster pumps, and have suctions to the fuel-oil tanks and to the booster pump discharge pipes.

5. *Hand Pumps.*—Small high-pressure pumps used to pump oil into the burners by hand when no steam is available.

6. *Pressure Oil Heaters.*—Appliances in which oil is heated by means of steam to reduce its viscosity, so that its atomization in the burners will be effected more readily.

7. *Strainers.*—Basket strainers fitted in the suction and discharge pipes of the booster and oil service pumps to remove dirt from the oil.

8. *Oil Burners.*—Devices to which oil is supplied under pressure, and in which it is atomized or broken up into minute particles so that it will burn more readily in the furnace.

9. *Air Registers.*—Devices in the casing of the boiler for admitting and regulating the supply of air for combustion of the oil in the furnace. The air registers are made in various shapes, cylindrical. conical and discal. The conical registers are also known as

air cones, and the discal ones as *impeller plates.* The burners are set in the registers and project toward the furnace space. Properly speaking, an air register should have a regulating shutter. Air registers are also called *tuyeres.*

10. *Meters.*—Oil meters on the oil service-pump suction or discharge, to measure oil consumed by the boiler.

11. *Heating Coils.*—Steam coils around the suction pipes in the fuel-oil storage tank to reduce the viscosity of the oil so that it may be drawn readily into the oil pump suction pipe.

12. *Automatic Stop Valves.*—Automatic valves placed in the oil service pump discharge pipe to cut off the supply of oil in case of rupture of the oil line to the burners.

13. Necessary fittings, such as valves, drains, gages, etc., to all the appliances previously given.

Fuel-Oil Piping.—Oil piping is made of seamless drawn steel with steel flanges. Either the flanges are screwed on with pipe threads and the pipe is expanded in the flange, or the pipe is expanded into grooves in the flange. All joints and fittings are made tight by metal-to-metal joints; *i. e.,* there are no gaskets used.* Suction pipes must be tight under a pressure of 50 pounds per square inch; and discharge pipes, under a pressure of 600 pounds per square inch. On vessels using fuel-oil as auxiliary with coal, suction pipes lead from the double-bottom storage tanks to engine room manifolds. Heavy simplex pumps in engine rooms discharge the oil through strainers into a main, branching in the fire rooms to run outboard of the boilers and to thus supply the burners through pressure oil heaters. A storage tank filling pipe runs under the main deck from side to side, having hose connections at the sides. A vertical pipe connects this athwartships pipe with a cross-connecting pipe between the suction manifolds. Heavy air chambers are located on the suction and discharge sides of the simplex pumps.

Fuel-Oil Storage Tanks.—The liquid fuel is placed in oil storage tanks; each tank has suction pipes leading to the storage-tank manifolds in the fire-rooms. The oil storage tanks, in battleships, are specially constructed structural compartments. In destroyers, they are specially constructed tank compartments, forward of the fire-rooms and abaft the engine-room.

The double bottom storage tanks on *battleships* using coal and oil have each the following connections, besides suction piping:

1. Vent pipe (sheet iron) leading from tank top to main deck (well screened).

2. Sounding tube (wrought iron) with valve, cap, and locking device.

* In practice, gaskets sometimes have to be used; in such cases they are made by using between the flanges a coat of shellac or oil paper. The oil paper can be made by soaking a piece of an old chart in oil.

3. Steam connections for fire extinguishing and for steaming out the tank.

4. Salt water connection for expelling gas and for cleaning.

5. Warning device and automatic float cut-off valve, to operate when the tank is 95 per cent full.

The storage tanks of *battleships* using fuel-oil only are double-bottom compartments forward of the fire rooms, and abaft and under the engine rooms, and other special compartments not directly adjacent to heated compartments. They are provided with two suction pipes called high and low, the latter being used for draining off water or when oil is low, with viscosity reducing steam coils, with vents, with steam fire connections, and with measuring device. The storage tanks of *destroyers* make use of the vessel's skin as parts of the tanks, and often extend from side to side. Each tank is fitted with these connections:

1. One or more air escape and overflow pipes (iron), fitted with valves and mushroom heads.

2. Sounding tube (wrought iron), with guard at lower end and plug and lock at upper end.

3. Steam connections to near bottom for reducing oil viscosity and at top for fire extinguishing.

4. Filling connection.

5. Manhole and manhole plate with lock.

6. Drain pipe from tank bottom.

Storage tanks require special joints. Flange joints outside of tanks are made with two layers of No. 10 canvas soaked in raw linseed oil and painted with thick red lead. Their through bolts are packed under heads and nuts with lamp-wick soaked in red lead. These joints are sometimes made with pasteboard saturated with a mixture of 20 parts wax and 10 parts varnish. The rivets are closely spaced and seams are calked on both sides.

The amount of oil in a storage tank is registered by an instrument called a pneumercator (see page 232).

Booster Pumps.—The booster pumps are similar in design to the simplex piston type of pump described under feed pumps, though not constructed to give such heavy pressures, hence they are sometimes called light-service pumps. They have metallic valves, and have large vacuum chambers on their suction sides and large air chambers on their discharge sides. They have suctions to storage-tank manifolds and to the filling pipe connected to the ship's side. They have discharges to storage-tank manifolds, fuel-oil main, service pump suction, and main deck for supplying galley. They have also a discharge at ship's side for oil transference and an arrangement, by portable connection, for discharging overboard oil or water from the tanks.

There are strainers of the basket type both on the suction and on the discharge sides of these pumps.

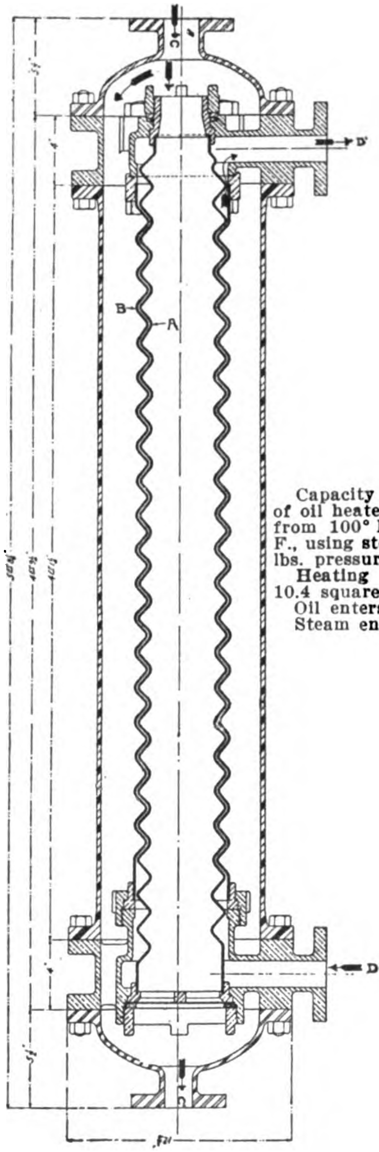
Duplex oil service pumps of the piston or plunger type are installed in each fire-room; they have suction pipes through twin-basket strainers leading to oil storage tank, fuel-oil main, booster pump discharge, and to burner supply line for draining it, and have discharges through duplex basket strainers to oil pressure heaters, and from the heaters to the burner supply pipes for all boilers. These are heavy-pressure pumps. These pumps have large vacuum chambers on their suction sides, and large air chambers on their discharge sides. In the discharge pipe from the pressure heaters to the burners of each boiler, there is a master valve fitted; this valve is so arranged that it can be operated from the deck above. It controls the oil supply to all burners of one boiler. The following fittings, besides those already mentioned, are attached to each of these pumps: pump governor, adjustable spring relief valve, and pressure gages (on discharge pipe, each side of strainer).

Hand Pumps.—One hand oil service pump is installed in each fire-room for use when getting up steam in one of the boilers of that compartment when there is no steam on the vessel for running the duplex oil service pumps. These pumps supply oil at a pressure of 200 pounds per square inch to two burners. Each has a suction to the fuel-oil main in its compartment and discharges to the burner supply pipe. It also has a suction to the storage tank drains, and a discharge overboard, by means of which the water may be pumped overboard from the bottom of the storage tanks.

The pressure oil heaters are located in each fire-room, and have sufficient heating surface to heat all the oil used in the boilers in that fire-room when steaming at the maximum rate of combustion. The oil may be heated to any desired degree, but should never be heated above flash point. They are similar in design to the pressure feed-water heaters. (These feed-water heaters have been described in an earlier part of this chapter.)

The Schutte-Koerting Film Heater installed on the *Utah* is shown in Fig. 75.

The pressure heaters are so arranged that they can be bypassed if desirable. The heaters take steam direct from the auxiliary steam line and are drained to the feed and filter tanks through traps.



Capacity 6000 lbs. of oil heated per hour, from 100° F. to 250° F., using steam at 200 lbs. pressure.
Heating surface, 10.4 square feet.
Oil enters at D.
Steam enters at C.

FIG. 75.—Schutte-Koerting Film Heater.

These traps have gage glasses and fittings, by which the condensed water may be drawn off and tested for oil. The gage glass should be carefully watched, as oil leaks may be detected at this point, thus preventing fuel oil from getting into the boiler feed.

Oil heaters of the straight-flow and coil types are also used.

Oil Strainers.—Twin-basket strainers are fitted, and are so arranged that one strainer can be bypassed and the basket be removed and cleaned while the other is in use. The twin-basket strainer shown in Fig. 76 is made by the Elliott Company. The ends of the compartments *A, A* can be easily removed, and basket be removed

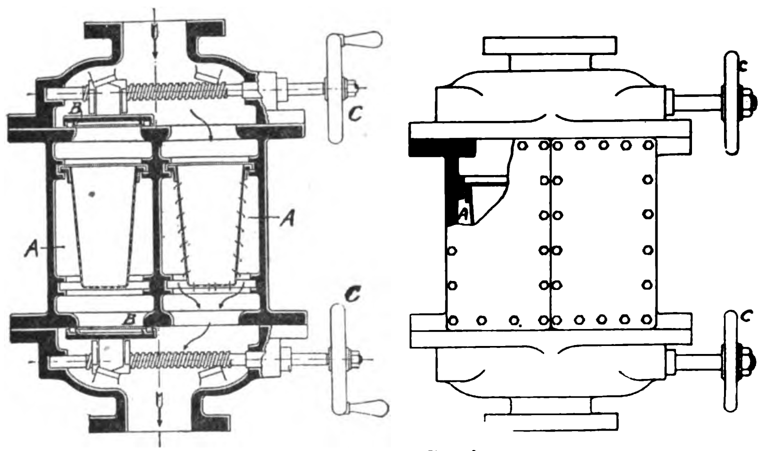


FIG. 76.—Elliott Strainer.

and cleaned. The valves *B, B,* operated by hand wheels *C, C,* direct the oil through either one or the other of the baskets.

Oil Burners.—There are three classes of burners for liquid fuel. The classification is made with regard to the method used in atomizing the oil by the burner.

The three methods of atomizing the fuel are: (1) *Steam atomization,* (2) *air atomization,* (3) *mechanical atomization.*

The *steam atomizing burners* use from 3% to 5% of the steam generated by the boiler, and are therefore impracticable for marine use on account of the fresh water required to make up for that expended in the burner.

Air atomization requires large, heavy air compressors to give air under the requisite pressure for atomization. While this system

entails no loss of fresh water, it requires much steam to give the necessary power for compressing the air. The compressors take up much room and require special attendance.

Mechanical atomization is accomplished by having the oil in the burner under a comparatively high pressure. Both the shape of the burner nozzle and the internal fittings of the burner play an important part in the character of the atomization.

The oil service pumps give the required pressure (about 200 pounds), and they are attended by the regular fire-room force.

Mechanical atomization is the only practicable method for use with marine boilers at present, and is the only method in use, at sea, in the navy. For use *in port,* to avoid the large steam consumption of the blowers, the Ingram burner (a steam or air atomizer) has been in extensive use. Air compressors are fitted on some destroyers to provide for air atomization in port.

There are oil strainers fitted to each individual burner. They are so designed that they may be easily and quickly opened, cleaned, or removed without interference with other burners.

Burners are fitted in air registers.

In the burners now in use, the atomization is caused by the action of centrifugal force when the oil is given a rapidly revolving motion in the burner. The spray of oil issues from the burner tip in a cone without a whirling motion.

The burners are usually arranged to diverge in the direction of discharge, in order to prevent the flames from impinging on each other, and are always arranged to discharge so that the flame will not impinge on the lower row of tubes or on any part of the heating surface of the boiler. They are so fitted that the tips of the burners are in the furnaces, and the service pipes and regulating valves are in the fire-rooms.

As previously stated, all burners for mechanical atomization of oil incorporate the principle of forcing oil under high pressure through passages in the burner so arranged as to give the oil a high velocity of rotation and thus break it up under the action of centrifugal force. The rotary motion is given either by a helical construction of the atomizing head or by a tangential entry of the oil from a peripheral to a central passage in the head. The capacity of the burner, *i. e.,* the quantity of oil burned per hour, depends upon

the pressure and temperature of the oil and the diameter of the opening in the burner tip, increasing up to certain practical limits with the increase of these two factors. In some types of burners, the capacity of the burner may be varied by changing the openings of the passages in the atomizer head by means of a regulating spindle projecting into the passages. This construction makes the burner more complex and introduces the probability of being unable to adjust the openings of all burners exactly the same. For use in port, extra burners of reduced capacity are now supplied.

The principle of all mechanical atomizing burners will be understood from a study of the Bureau of Steam Engineering Standard Burner, Plate XVI.

Oil under pressure enters the burner through the oil pipe and passes through the burner pipe to the burner plug. Here it passes through ports P_1 and P_2 to the outside of the end of the plug, which is reduced in diameter to form a space S, from which the oil enters four tangential slots TS and is directed inward from S to the atomizing chamber AT. From the chamber AT the oil is sprayed through the central outlet passage O in a finely atomized cone. The ball-and-socket joint at the elbow permits the removal of the burner for examination or repair. The burner tips are removable. The angle of the oil cone is 90°. A slight variation from this angle does not affect the efficiency of the cone.

The **Ingram burner**, which is used in port by the destroyers and which employs either steam or air to atomize the oil, is shown in Fig. 77. Steam or compressed air enters the burner at the pipe marked "steam," and goes out through pipe *a* to the burner tip; oil enters from below and reaches the tip through the pipe *b*. At the tip the oil works down through the five channels marked *c* (end view) and is blown out through the narrow horizontal slot by the compressed air. The oil leaves the burner in a narrow sheet which widens as it advances.

Oil Fuel for Battleships.—In battleship boilers fitted to burn coal and liquid fuel, both singly and together, the arrangement of the burners and furnace doors is such that no change in the furnace fittings is necessary to shift from coal to liquid fuel, or *vice versa.* The burners are fitted in pairs through the furnace fronts between the furnace doors, and are so arranged that either burner and its strainer of the pair can be in operation while the other one of the pair is being cleaned or overhauled. When boilers for battleships

are designed for use with liquid fuel only, the arrangement of their burners, air registers and air casings is similar to that in the present liquid-fuel-burning destroyers.

Air Registers.—The registers in use in the U. S. Navy are of two general types, the *conical* and the *discal.*

The conical type is made in the shape of the frustrum of a cone, with slots down the side of the cone of such cross-section as to give the air a rotary motion and with adjustable shutters to regulate the quantity and velocity of the air entering the slots. Registers of this type are commonly called *air cones,* and are now standard in

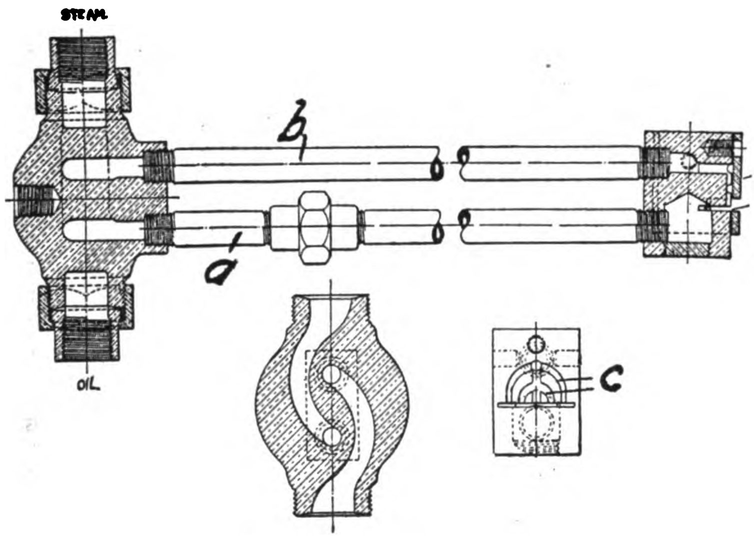


FIG. 77.—Ingram Burner.

the U. S. Navy. The cones are usually secured between the outer and inner plates of the boiler front casing. In some types of boilers where the air space between the outer and inner plates of the front casing is small, the cones are secured through both casings at their large ends and project from the boiler front into the fire-room.

The discal type is made from flat plates with radial slots of such shape as to give the air a rotary motion. It usually has no regulating shutter, the openings being considered with the design of the blowers and the air being regulated by doors in the outer casing. Registers of this type arc installed on some of the U. S. battleships. They are called *impeller plates.*

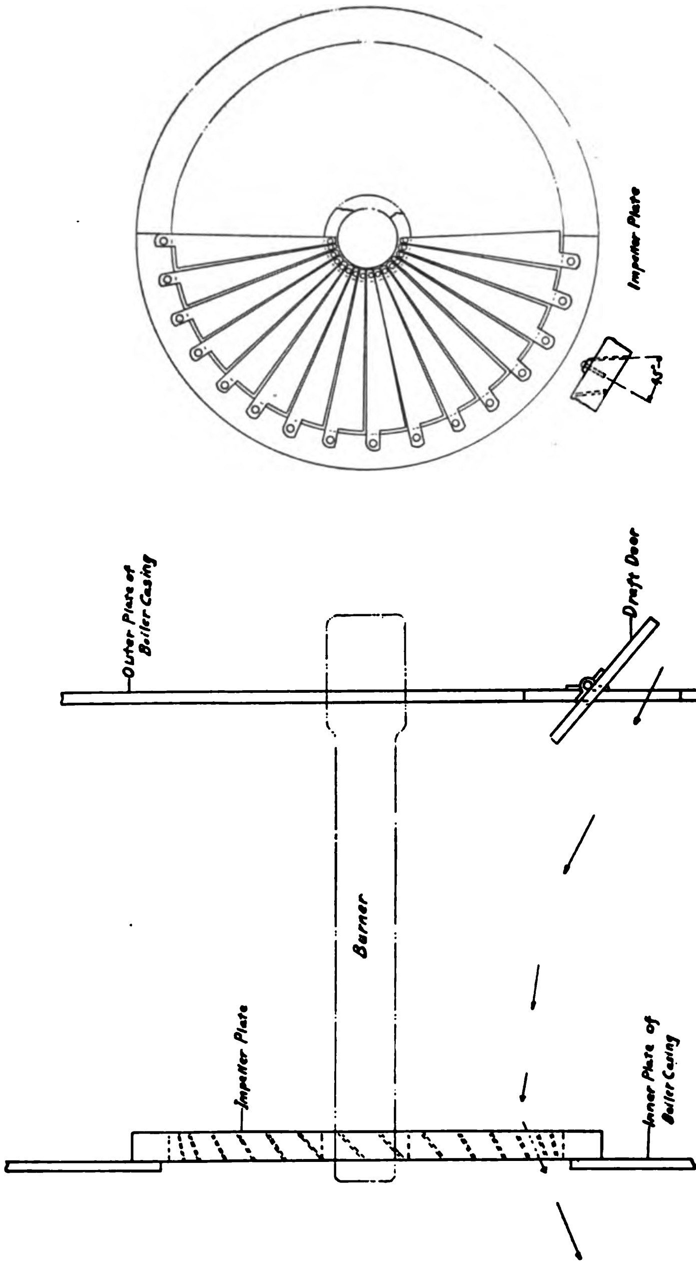


FIG. 78.—Diagrammatic Scheme of Installations Using Peabody Impeller Plates.

The Peabody Impeller Plate shown in Fig. 78 is fitted by the Babcock and Wilcox Company to their boilers burning oil alone or oil in conjunction with coal. The vanes of the impeller are set at an angle of 45° to the plane of the impeller plate. Air is admitted to the space between boiler front plates by non-return swing doors, as shown. Air is supplied by blowers under the closed fire-room system.

Bureau Engineering Natural-Forced Draft Register (Plate XVII).—The details of the earlier registers varied considerably. The principle of all may be understood from the sketch of the Bureau of Engineering Natural-Forced Draft Register, Plate XVII, which incorporates the ideas of most of them.

The register 1 is bolted through the angle ring 4 and straight ring 3 to the boiler front. Details of air register are shown in small sketch. The position of the atomizer 36 is controlled by means of a rack, not shown, on pipe 37 and pinion 28 operated by handle 32.

(a) Firing Accessories for Coal-and-Oil-Burning Boilers.

Tools and Appliances for Handling Ashes and Soot.

Ash buckets are cylindrical buckets with extra heavy bottoms. They have a bail pivoted in pads on the sides of the bucket near the top. The bail has an eye or bend at its center part, into which the hook on the ash hoist-engine wire engages when hoisting ashes. These buckets hold approximately 100 pounds of ashes when filled.

Ash hoist engines are simple steam engines operated by a differential valve. There are generally two simple steam cylinders working on the ends of the same shaft. The shaft operates a drum around which the hoist wire is wound. The valve is operated by a hand wheel, which works through a gear and opens the valve as the wheel is turned. A chasing gear on the shaft operates to close the valve as it is turned. By moving the hand wheel, the valve is opened and steam is turned into the engine cylinder; and as the engine moves, the valve is closed by means of the chasing gear. As long as the hand wheel is moved, the engine continues to operate; as soon as the motion of the hand wheel is stopped, the engine stops. There are lugs on the hand-wheel shaft which are so located that the engine cannot be operated to hoist the bucket too high, also to prevent it being dropped to the floor plates with too much force. The wire from the drum leads over sheaves; it hoists or lowers the bucket between guides placed in a fire-room ventilator or vertical air duct.

Ash ejectors are now fitted to all new coal-burning battleships and armored cruisers, and have been installed on most of the old ones.

There are two classes: (1) Those that discharge the ashes *above the water-line* and (2) those that discharge *through the sides or bottom* of the ships.

There are several makes of each class. The ones, of the first class, used in the navy are the Davidson and See, which consist of hoppers into which the ashes are thrown, and from which they are removed by the action of a jet of water under pressure. The ashes are forced out through a cast-iron pipe leading to the side of the ship above the water-line. The pipe is made extra heavy at all bends, to allow for the scouring action of the ashes; in some cases the pipe has removable pieces placed at the outer curve of all bends. With ash ejectors of this type the water is forced into the pipe through a nozzle, thus forming the jet. The ashes are washed into the jet by

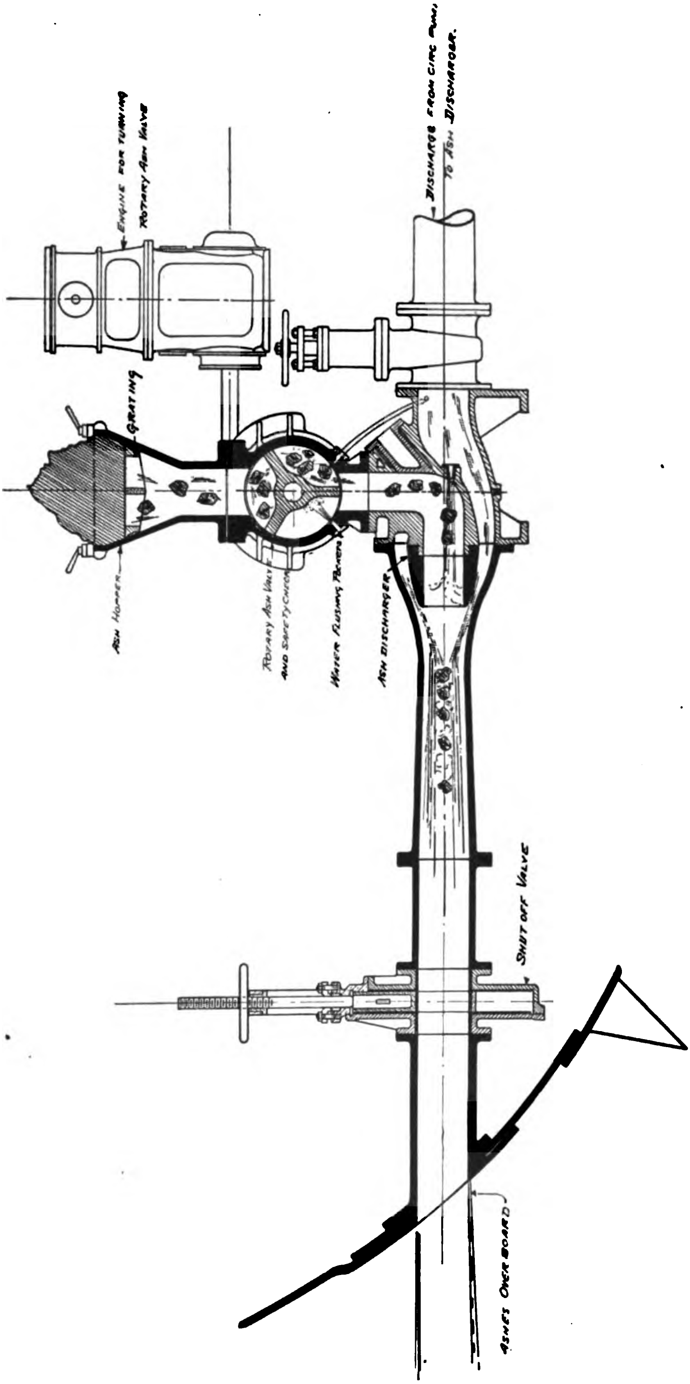


FIG. 79.—Under-water Horizontal Hydraulic Ash Discharger. (Section showing operation.)

small streams of water forced into the hopper around its sides, and also by the suction caused by the jet. Great care must always be taken to see that the nozzles are set with the proper opening to form the jet, and also that the jet is formed in the center of the pipe; otherwise the jet will cut the pipe, due to the scouring of the ashes.

There are two types of the under-water ash ejector—the pneumatic and the hydraulic. These types are coming into use on the newer ships. There was objection to this type for many years, as it was claimed that (1) the scouring action of the ashes wore away the outer plating, (2) the ashes entered the main injection pipes and clogged the main condensers, and (3) they entered the strut and stern tube bearings, causing them to cut and wear away rapidly. Objection (1) has little weight, objections (2) and (3) were overcome by placing the discharge orifice below the bilge keels, and this class of ejector is coming into general use.

A type of under-water ash expeller is the Newport News Shipbuilding Company's Ash Discharger, shown in Fig. 79.

Ash Wets.—In each fire-room a small connection is made to one of the sea suction-valve casings below the valve. This connection has in it a valve and a hose coupling. A small hose is secured to this for wetting down the ashes and clinkers when cleaning fires or for running water into the ash pans if necessary.

Tube blowers are for the purpose of removing soot and cinders from the fire side of the tubes; and there are many types in use. For fire-tube boilers a steam lance, connected to the auxiliary steam line by means of a steam hose, is generally used. The lance is placed in the outer end of the tube, and a jet of steam is blown through the tube, sweeping the soot and cinders into the combustion chamber.

For water-tube boilers the lance is connected to the auxiliary steam line in the same way as above. It is carried on a jointed handle, and is shoved in between rows of tubes; the steam jet blows the soot from the tubes. In cleaning tubes by blowing the soot from them by steam or air the path of the gases of combustion should be followed, beginning with that part of the path where the gases enter between the tubes; *i. e.*, in a Babcock and Wilcox boiler the first pass would be blown, then the second, and finally the third pass. After the tubes are blown, the soot and cinders should be raked from the upper sides of all nearby horizontal baffle plates.

In ships that have a pneumatic line running through the fire-rooms, a connection is made in each fire-room for blowing the tubes with compressed air.

In some types of water-tube boilers of recent manufacture, perforated pipes are fixed in position between the tubes, in locations where the soot and cinders are most likely to collect (see Plate V). Each of these pipes is connected to a branch from the auxiliary steam line, and steam is controlled by its own valve. This branch has a valve at the auxiliary line; below this valve a line connects the branch with the pneumatic line. Either steam or air can be used for blowing the tubes. In any case where the soot and cinders have become wet and packed too hard for removal by blowing, or where from leaky tubes salt scale has formed between them, the obstruction must be removed by scaling bars.

Tube brushes are used for removing the soot and scale from the fire sides of fire tube boilers. The one in general use in the navy is a metal cylindrical brush with the metal bristles arranged around its stem in the form of a helix (see Fig. 81). The brush is screwed into a handle and is worked back and forth through the tube until it is clean. The same style of brush is used for removing a light mud scale from the water sides of water tubes.

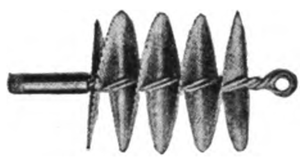


FIG. 81.—Wire Tube Brush.

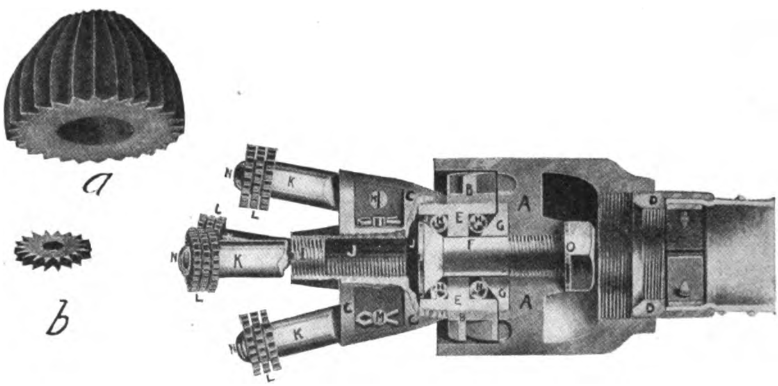
Scale-Removing Tools.

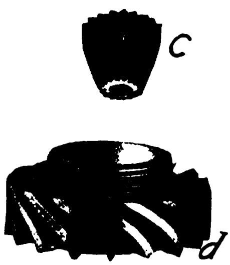
Tube cleaners, for removing the hard scale and rust from the water sides of water tubes, can be subdivided into three general classes: (1) Those that remove the scale by *hammering,* (2) those that *grind* it away and (3) those that *scrape* it from the metallic surface.

The first two classes are generally turbine-driven, either air or water, under pressure, being used as the motive power. Most turbine cleaners have cutters so arranged that one set does the hammering while another set does the cutting.

Fig. 82 shows the Weinland water-driven turbine cleaner, with different cutters shown at *a, b, c.* *d* is the turbine wheel.

The hose *D* connects the chamber of the turbine with the pump discharge. The water passes through the buckets of the water wheel *B* and gives a turning motion to spider *C;* the arms *K,* carrying the cutters *L,* are thrown out against the sides of the tube by centrifugal action, and the cutters grind away the scale. The water,





A—Case.
B—Water wheel.
C—Spider.
D—Hose coupling.
E—Ball-races.
F—Center bolt.
G—Cone.
H—Balls.
I—Screw for oil chamber.
J—Oil chamber.
K—Arms.
L—Cutter wheels.
M—Arm Screws.
N—Cutter pins.
O—Nut for center bolt.

FIG. 82.—Weinland Turbine Tube Cleaner.

after it escapes through the water wheel, washes away the scale as it is ground off. These cleaners are made in sizes to fit the tubes, as required.

Turbine cleaners must be used with care; if they are held too long in one place, erosion of the tubes will result.

Dampers.

Dampers are heavy doors placed in the uptakes of boilers for regulating the amount of air flowing through the furnace, and thereby regulating the rate of combustion. They also prevent air from being drawn into the smoke-pipe through idle boilers connected to the same pipe. These dampers are so arranged that the amount of opening may be varied at will from closed tight to full open. They must be made heavy to prevent warping under heat; must be maintained in such condition that they can be closed tight; and must be capable of easy control.

Blowers.

There are two methods of increasing the draft of air through the fuel of a furnace: (1) By using *air or steam jets* in the base of the smoke-pipe; these create a partial vacuum and cause a greater flow of air through the furnace and a higher rate of combustion; (2) by using *mechanical blowers.* The first method is impracticable for use with marine boilers, as too much fresh water would be used with steam jets, and the machinery necessary to furnish compressed air for the air jets would be too heavy. The second method, that of forcing the air through the furnaces with *blowers,* is the one used in naval vessels.

Forced-Draft-Blowers.—There are two systems in use for forcing the draft with blowers: (a) The *closed ash-pit system,* in which blowers draw air from an air duct or from the top of the fire-room and discharge it into the ash pans and air casings of the boilers through air ducts; and (b) the *closed fire-room system,* in which the blowers draw air from an air trunk, open to the atmosphere at its upper end, and to the blower suction at its lower end, and discharge the air into closed fire-rooms, from which it can escape only through the furnaces. The closed fire-room system is the one in general use.

The blowers in use, both in the closed ash-pit system and in the closed fire-room system, are high-speed centrifugal fans. Air is drawn in at the center of the fan and discharged at the periphery, either into the closed fire-room or into ducts leading to the ash pits and air casings.

The complete blower consists of: (1) The *motive power,* a steam engine, a small steam turbine or an electric motor; (2) the *fan;* and (3) the *fan casing.*

Fig. 84 shows a sirocco fan connected to a Terry steam turbine. The casing of the fan (not shown) has a suction, opening at its center, leading to the air trunk, and discharges at the periphery of the fan into the trunk leading to the closed ash pit or into the closed fire-room. The latest battleships have motor-driven fans with the

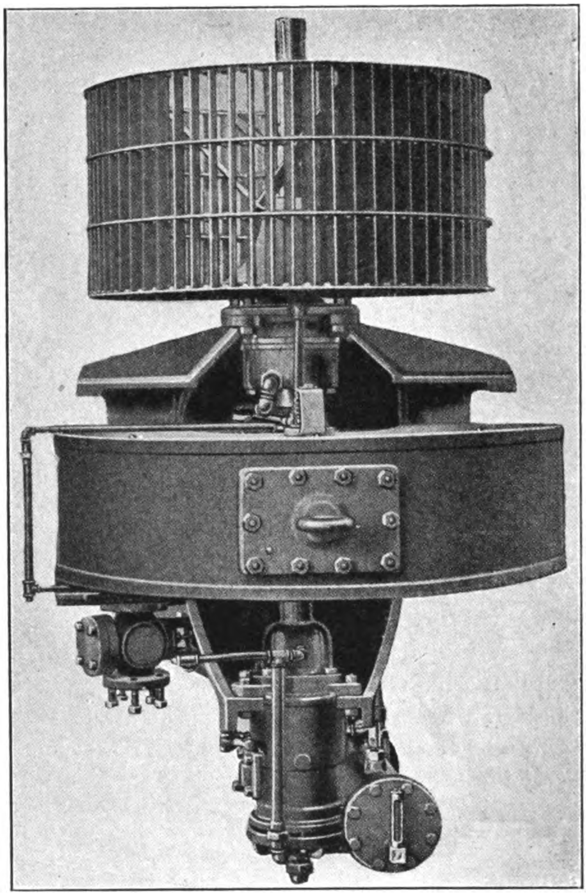


FIG. 84.—Terry Steam Turbine and Sirocco Fan.

motor control, which will give at least ten different speeds, operated from the fire-room floor plates.

The blowers are placed in the upper part of the fire-rooms. Provision is made for circulating the air in the upper part of the fire-rooms to prevent the accumulation of explosive liquid fuel gases. In some cases, where the blower fans are driven by steam engines or turbines, an automatic control of the blower speed is installed, by

means of which, when the steam pressure falls, the control valve to the engine is opened and the draft pressure is increased. If the steam pressure rises above that for which the control is set, the engine valve is partially closed and the draft pressure decreased.

PART IV. TESTING ACCESSORIES.

A description of the testing accessories will be found in the Appendix.

PART V. MISCELLANEOUS ACCESSORIES.

Whistles and Sirens.

From the auxiliary steam line, branches are taken and extended forward of the forward smoke-pipe to a height well above the bridge. A whistle is attached to one of these pipes, and a siren to the other. There are valves to the branches where they are taken from the auxiliary steam line; valves are also placed in the supply lines just below the whistle and siren, at positions easily accessible from the bridge. The valves near the bridge are for use in shutting steam off the whistle and siren in case either should be jammed open while in operation; in case these valves are not installed, the order from the bridge must be telephoned to the engine-room and transmitted to the forward fire-room, and a man be sent up to close the branch stop valve—an operation taking appreciable time from the instant the defect is noted until the valve is closed. All whistle and siren steam pipes should have a separator installed just below the whistle or siren.

One form of this separator, called a *water arrester,* is shown in Fig. 85. The arrows on the sketch show the path of the steam. Water is collected in the bottom of the arrester and blown out through an automatic trap. The drain answers two purposes: (1) To ensure the proper sound the instant the steam reaches the whistle or siren, and (2) to prevent water being blown out on the bridge or deck when the valve is first opened.

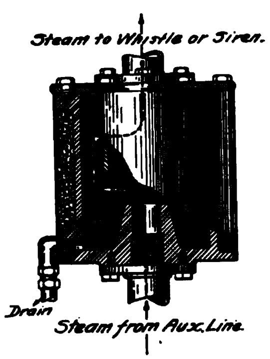


FIG. 85.—Water Arrester.

Drains from the branches from the auxiliary line are also fitted just above the branch stop valve and connected to a trap. These drains are to drain the pipe when steam is shut off at the branch stop valve, to prevent the pipe from bursting in freezing weather.

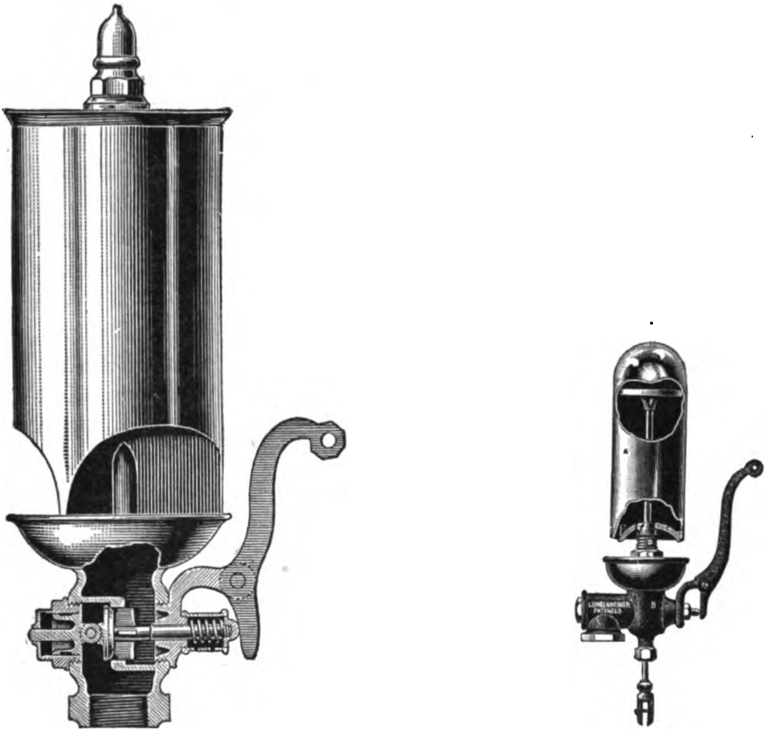
The tone of a whistle depends chiefly upon the pressure of the steam or air blowing through it and the length of the column of air or steam inside of the bell. In most whistles the length of the bell can be varied, as will be shown later. When a whistle is installed, it should have a reducing valve installed in the branch steam line leading to it. The bell on the whistle and the steam pressure to it should be adjusted by trial, so that the whistle gives the tone and degree of loudness desired.

For navigation purposes the sound signalling apparatus on all steam vessels is the whistle. On naval vessels a siren and a whistle are both installed—the siren on the forward side of the forward smoke-pipe for signalling ahead, and the signal whistle abaft the after smoke-pipe for signalling to vessels astern. The siren is also used for signalling in the interior communication system of the ship itself.

The three most familiar forms of steam whistles are the *bell whistle, chime whistle* and *shrieking whistle*. They are all constructed on the same principle; the sound is produced by steam issuing from a narrow circular orifice and striking the thin edge of a cylindrical bell, which is secured at a certain distance above the orifice.

Chime whistles are no longer installed on naval vessels, though there are many now in use. Fig. 86 (a) shows a three-chime whistle made by the American Steam Gage and Valve Manufacturing Company. The bell is the long cylinder at the top, and is adjustable on a vertical central rod by means of a thread, the nut on top securing the bell in place. The cup-shaped part, immediately below the bell, contains a narrow annular orifice in its flat surface, through which steam passes from the operating valve below. There are three compartments in the bell, as shown, each of a different length and producing a different note. These notes harmonize under the proper conditions. Steam is admitted to the cup-shaped bottom of the whistle by a valve, which is opened against the steam pressure and a spring by the bell crank lever, operated from the bridge by means of the whistle pull. This valve is bypassed on whistles for some of the battleships and armored cruisers, and an electrically controlled valve is installed in the bypass. The current for operating the electrical control is sent through a clock-work mechanism, which can be set to blow the whistle at certain definite intervals of time, and by means of which the length of the blast can be regulated.

The **bell whistle** is similar to the chime whistle, except in the make of the bell. It is not cut away at the bottom as in the chime whistle, the interior being a plain cylinder not subdivided. Only one note is produced by a bell whistle with a given adjustment of the bell and the steam pressure; so a reducing valve, set at the pressure to give the proper note, is a necessity.



(a) Chime Whistle. (b) Shrieking Whistle.

FIG. 86.—Forms of Whistles.

The **shrieking whistle**, shown in Fig. 86 (b), made by the Lunkenheimer Company, is similar to the bell whistle, except that there is a movable piston inside of the bell, by means of which the length of the column of air can be changed at will, and a succession of rising or falling notes be produced. The adjusting thread and nut are, in this case, below the bell.

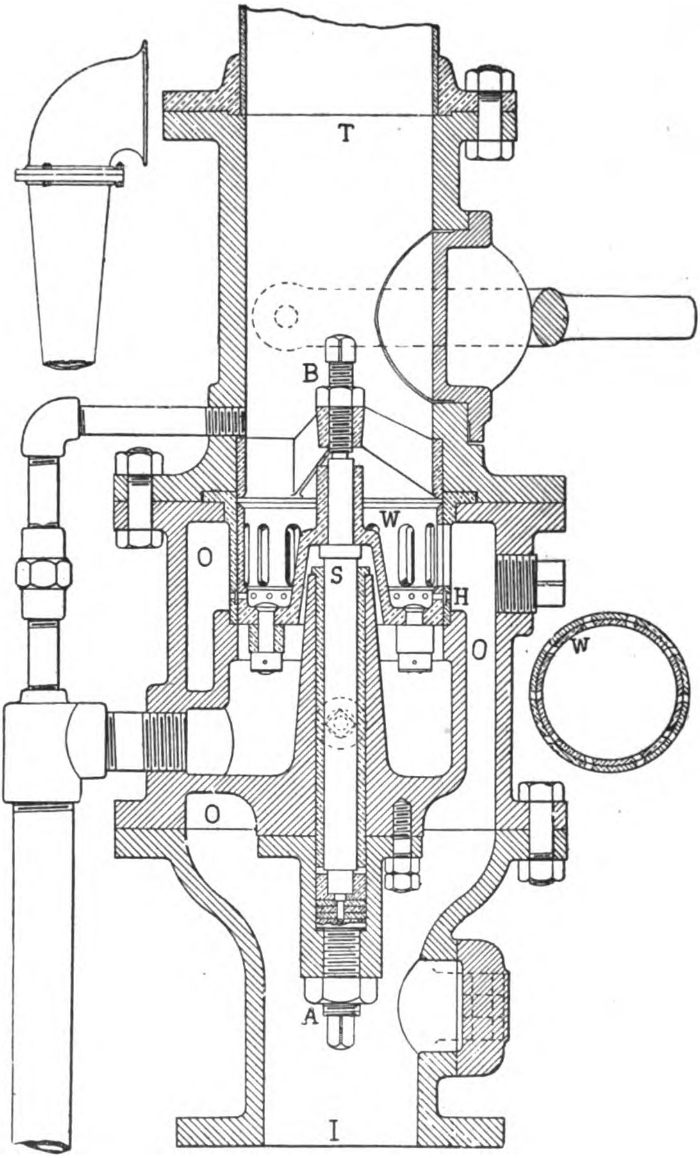


FIG. 87.—Steam Siren.

The **siren** is a more powerful instrument than the whistle. It is made with a trumpet mouth or megaphone, which can be turned to project the sound in practically any direction, thus making it more efficient as a fog signal than the whistle. Fig. 87 shows the form of siren used in the naval service. Steam is admitted at *I* by means of a valve (not shown) similar in construction and control to that of the whistle. Steam fills the annular chamber *O*, which is pierced at its upper inner part by a number of vertical bevelled slits. A cup-shaped wheel *W*, pierced by similar slits, but bevelled in the opposite direction (shown in the small sectional view), is fitted to revolve freely on the central spindle *S*. As the steam from *O* rushes through the outer slits and against the sides of the slits in *W*, it causes the latter to revolve at a high rate of speed. The alternate closing and opening of the slits sets up violent vibrations in the column of air and escaping steam in the megaphone or trumpet-shaped outlet fitted above *T*. The pitch of the sound will depend on the speed of the wheel, which, in turn, depends upon the opening of the controlling valve for any constant pressure. Should the wheel, when it stops revolving, close all of the outer slits, the siren can still be started by means of the auxiliary holes *H*, the spacing of which is different from that of the slits. In other forms of sirens the slits are spaced unevenly, and no auxiliary holes are necessary. The method of balancing and supporting the wheel is shown. *A* and *B* are adjusting bolts for the spindle, access to which is given by the hand holes. The trumpet mouth or megaphone, shown to a reduced scale, is fitted to turn, either directly by a handle, or by means of gearing from below. Drains are fitted to the spaces both above and below the wheel *W* in cold weather; the siren must always be properly drained.

Calking Tools.

There is much difference of opinion in regard to the proper shape of the calking tool and the proper shape of the plate edges in order to obtain the best results in calking seams.

The illustrations of the tools used, and of the results obtained from the way of holding them, shown in Fig. 88, are from Stromeyer's Marine Boiler Management and Construction, 1907 edition.

1 shows the shape of the calking tool and the proper way to hold that tool when the edge of the plate is square; 2 shows the result of calking a seam in this manner, giving fair results; 3 shows the same tool improperly held when the edge of the plate is bevelled; 4 shows the result of calking a seam in this manner, the result being bad; 5 shows the proper way to hold this tool against the bevelled edge of the plate, and 6 shows the plates after calking.

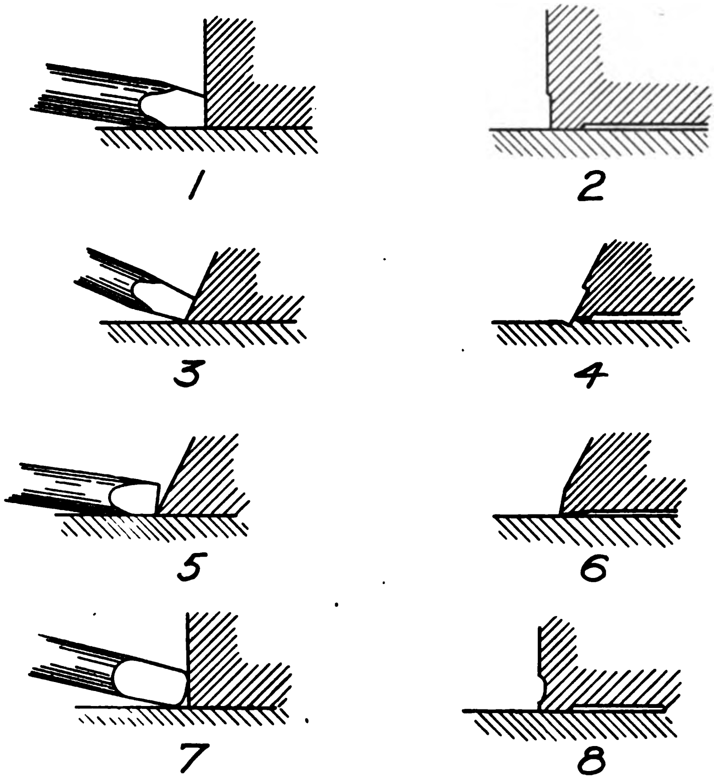


FIG. 88.—Calking.

Although the tool is held properly the result is not good, and a better result would be obtained from the use of the tool shown in 7; 7 shows proper way to hold a round-nosed calking tool against a square-edged plate, and 8 shows the result after calking. In calking with this shape of tool, care must be taken that it is not too small, as it will then act as a wedge and separate the plates. Care must also be used in grinding the flat-nosed tool; if the tool has too much bevel, the lower edge will bite into the lower plate.

Tube Expanders.

The **boiler tube expander**, shown in Fig. 89, is of the Dudgeon improved type. It consists of the body *A*, inner cap *B*, outer cap *C*, case-hardened rollers *D* rolling in slots *E* in body *A*, and the case-hardened tapered mandrel *F*.

The rollers *D* extend through the body *A* and are held in place in the slots *E* by the curvatures of their sides. Rollers can be replaced by removing cap *B* and renewing the roller in slot *E*. The body *A* is placed in the tube, and the cap *C* is adjusted over the end of the tube so that the roller extends completely over the tube in wake of the tube sheet. The mandrel *F* is then placed through the central hole in body *A* and bears on rollers, forcing them out against the tube. A bar is then placed through hole *G* in the outer end of *F*,

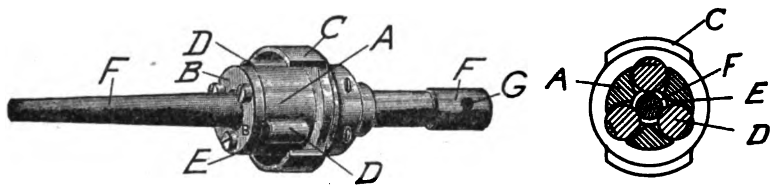


FIG. 89.—Boiler Tube Expander.

and the mandrel is revolved. After the rolls have rolled over the surface of the tube, the mandrel is driven in and revolved again. When done properly, this expands the tube against the tube sheet and makes a steam-tight joint.

In some tube expanders the rollers are so fitted that they feed the mandrel through as it is revolved.

Great care should always be taken, in rolling a tube, to see that the expander is properly placed, *i. e.*, that the rolls extend on each side of the tube sheet and that the tube is only expanded enough to make it tight. A great many boiler troubles are caused by improperly rolled tubes.

The latest practice is to have the ends of the tubes extend through the tube sheets or headers a distance of $\frac{3}{16}''$, and to bell the ends by an abrupt taper mandrel to $\frac{1}{8}''$ greater outside diameter. This prevents the tube from drawing through the tube sheet or header.

All tube ends are rounded before the expanding tool is used.

CHAPTER VI.

HEAT, HEAT TRANSFER AND EVAPORATION.

Heat.

Heat, according to the accepted modern theories on the subject, is a form of energy. It is usually given the name *thermal energy,* to distinguish it from other forms of energy. Since there exists a definite relation between these forms of energy, thermal energy may be converted into mechanical energy, or *vice versa.* The experiments of Rumford, Davy and Joule give ample proof of these facts.

Thermal energy is inherent in all solid, liquid and gaseous bodies, and is due to the velocities and relative positions of the molecules in the bodies. Like mechanical energy, it may exist either in the kinetic or in the potential form. It is measured by observing its effect upon some body.

Usually, when heat is added to a body, it results in either the expansion of the body, or an increase in its temperature, or both. The rise in temperature is a measure of the increase of its thermal kinetic energy due to the increased velocity of its molecules. Thus, if the velocity of a molecule is denoted by v and its mass by m, the kinetic energy of the molecule is $\frac{1}{2}mv^2$ and that of the system (total number of molecules under investigation) is $\Sigma \frac{1}{2}mv^2=Mc^2$, where M denotes the mass of the system. Considerations derived from the kinetic theory of gases show that c^2 is a function of the temperature of the system. Therefore, the temperature of a body or system is a measure of its thermal kinetic energy.

When a body expands, due to the addition of heat, the molecules on the whole are relatively further apart, and this separation of the molecules against their mutual attraction involves the expenditure of work or of its equivalent in heat. The energy utilized to separate the molecules of a body is stored up in the body as *potential thermal energy.* Kinetic and thermal energy may be well illustrated by the familiar example of heating water.

When heat is first added to a quantity of water, the effect is an increase in the temperature of the water, because the volume of water

changes very slightly, and practically all of the heat is used to cause a rise of temperature, that is, an increase in kinetic thermal energy. As soon as the water starts to boil, if more heat is added, there will be no further increase in temperature, but the water will be converted into steam, having a relatively large volume in comparison with the water from which it was evaporated. In this case, the energy of the steam has been transformed into potential thermal energy and remains stored up in the steam as such. After all the water has been converted into steam, if heat is still applied, there will be an increase in both temperature and volume; or, in other words, the additional heat is manifest in the steam in the form of an increase of both kinetic and potential thermal energy.

It is evident, therefore, that quantities of heat may be measured by their effects on different bodies in various states of aggregation. In the United States the standard *unit of heat* is the *British Thermal Unit* (B. T. U.). It is the 1/180 part of the heat required to raise the temperature of a pound of pure water from the freezing point to the boiling point at standard atmospheric pressure. In the C. G. S. system, the unit of heat is the *calorie*. It is the heat required to raise 1 gram of water from 17° to 18° C. on the Paris hydrogen scale.

Temperature and Sensible Heat.—*Temperature* is a measure of the intensity of heat, and is expressed in degrees by thermometers and pyrometers. These instruments may be standardized by noting their readings at certain known temperatures, such as the melting point of ice (32° F.) and the boiling point of pure fresh water (212° F.) at mean atmospheric pressure.

Sensible heat is the heat which, when added to or taken away from a body, will cause a change of temperature in that body.

Mechanical Equivalent of Heat.—Since thermal and mechanical energy are interconvertible, a definite ratio must exist between their units of measurement. This ratio was first determined by Joule as 772 foot-pounds to 1 B. T. U. The value was later more accurately determined by Rowland at Baltimore as 778, and this value is now generally accepted as correct. (777.5 foot-pounds of work = 1 B. T. U. is sometimes used.)

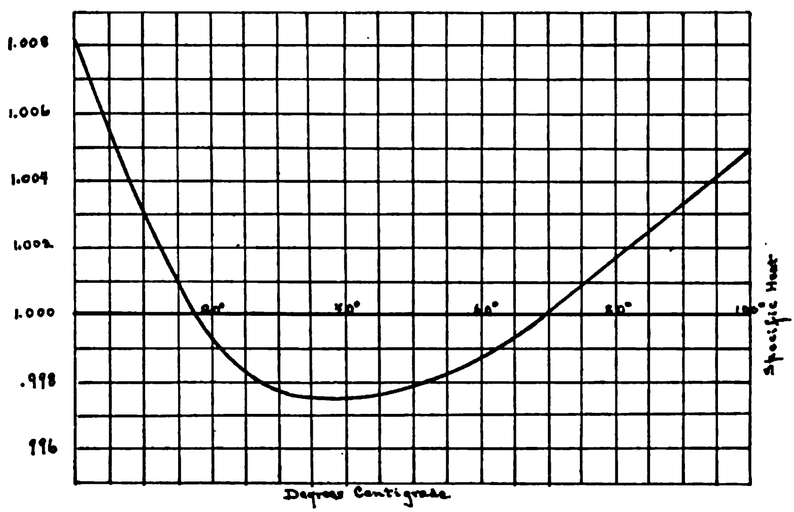
Therefore 1 B. T. U. is equivalent to 778 foot-pounds of work, or 778 foot-pounds of work are required to raise the temperature of 1 pound of water 1/180 of the temperature rise from 32° to 212° F.

Specific Heat and Thermal Capacity.—The quantity of heat required to raise 1 pound of a substance 1° F. under given external conditions is known as the *thermal capacity* of the substance for these conditions. Thus, if a quantity of heat, Q, is added to a body of weight M, causing a temperature rise from t_1 to t_2, the quotient, $\frac{Q}{M(t_2-t_1)}$, equals the *mean thermal capacity* of the body. The mean thermal capacity of a body at some given temperature, compared with the mean thermal capacity of an equal weight of water at some standard temperature, is known as the *specific heat* of a body. The standard temperature is generally taken as 63.5° F., and therefore

$$c = \text{specific heat of a substance} = \frac{\text{thermal capacity of substance at } 63.5°\text{ F.}}{\text{thermal capacity of water at } 63.5°\text{ F.}}$$

Now, the thermal capacity of water at 63.5° F. is equal to 1; therefore, the ratio of the heat absorbed divided by the rise in temperature due to this heat absorption is a measure of the mean specific heat of the substance.

In general, the specific heat of a substance is variable, and changes with the temperature. The specific heat of water is not constant, and varies with the temperature as illustrated in the chart below.



Variation of Specific Heat of Water

When dealing with gases and vapors, it is necessary to distinguish between specific heat at constant pressure and specific heat at constant volume. Thus, if a gas is heated in a closed vessel and is not allowed to change its volume, the heat absorbed divided by the temperature rise gives the mean specific heat at constant volume and is denoted by c_v. Therefore, $MC_v(t_2-t_1)$ is equal to the heat absorbed and is a measure of the increase of the kinetic thermal energy of the gas. (M=weight of gas heated.)

If, however, the gas be allowed to expand, due to the addition of the *same* quantity of heat, the pressure being kept constant, the rise in temperature will not be so great as in the first case, since part of the energy of the heat absorbed has been used to separate the molecules against their mutual attraction in order to increase the volume. From these considerations it is clear that, for a given increase in temperature, more heat is required to obtain the increase in temperature when the pressure is kept constant than when the volume is kept constant during the addition of heat. Therefore, c_v is always less than c_p. For a so-called perfect gas, there is a definite ratio between c_v and c_p given by $\frac{c_p}{c_v}=k=1.4$.

The ratio is approached by many simple gases, such as H_2, N_2, O_2, etc.

In general, for gases the specific heats are given by the following formulæ:

$$c_v=a+bt, \quad c_p=a'+b't,$$

where a, a' and b, b' are constants depending on the gas, and t is the temperature.

It has been found, however, that while the specific heats of simple and diatomic gases differ, their *molecular* specific heats are substantially the same.

Molecular specific heat is the specific heat of a unit weight of gas multiplied by its molecular weight, and is usually given by the expressions mc_v and mc_p, where m=molecular weight.

For simple gases,

$$mc_v=4.48+0.000667T, \tag{1}$$

$$mc_p=6.46+0.000667T, \tag{2}$$

where T is the *absolute* temperature. Therefore, to obtain the specific heat of a gas at a given temperature it is only necessary to divide equation (1) or (2) by the molecular weight of the gas.

Carbon dioxide (CO_2) and steam (or water vapor) do not follow the relations given in equations (1) and (2), but must be calculated from equations (3) and (4) and (5) and (6), respectively. For CO_2,

$$c_v = 0.12 + 0.000066T, \tag{3}$$
$$c_p = 0.165 + 0.000066T. \tag{4}$$

For steam (superheated),

$$c_v = 0.263 + 0.000133T, \tag{5}$$
$$c_p = 0.374 + 0.000133T. \tag{6}$$

Examples: Required the specific heat of oxygen at 40° F., the pressure being constant.

From equation (2),

$$mc_p = 6.46 + 0.000667T.$$
$$c_p = \frac{1}{32}\ [6.46 + 0.000667(40+460)],$$
$$c_p = \frac{6.7935}{32} = .2123.^*$$

In a *gaseous mixture* it is assumed that, for a given rise in temperature, each constituent requires the same quantity of heat that it would require if separated from the mixture. Therefore,

$$Q = M_1 c_{v_1}(t_2 - t_1) + M_2 c_{v_2}(T_2 - T_1) + \ldots. ;$$

but

$$Q = Mc_v(t_2 - t_1) \text{ in general. Therefore, since}$$
$$M_1 c_{v_1} + M_2 c_{v_2} + \ldots. = Mc_v,$$

where $M = M_1 + M_2 + M_3 + \ldots.$,

$$c_v = \frac{\Sigma M c_v}{M}, \quad c_p = \frac{\Sigma M c_p}{M}.$$

Example: A flue gas has the following constituents *by weight:*

CO_2	12.0
CO	0.4
O_2	9.6
N_2	78.0

Required the specific heat of the gas at constant pressure, at 440° F.

* In the Appendix will be found tables of specific heats of various substances.

Apply formulæ (2) and (4). Then $T=440+460=900$.

Constituent.	M.	m.	Mc_p.
CO_2	12	..	$12\,[0.165+0.000066(900)]$
CO	0.4	28	$\frac{0.4}{28}\,[6.46\ +0.000667(900)]$
O_2	9.6	32	$\frac{9.6}{32}\,[6.46\ +0.000667(900)]$
N_2	78	28	$\frac{78}{28}\,[6.46\ +0.000667(900)]$
	$M=100$		

$$\Sigma MC_p = 3.1\times 7.06 = 21.886$$
$$12 \times .2244 = 2.693$$
$$24.579$$

$$\therefore\ C_p \text{ for mixture} = \frac{24.58}{100} = .2458.$$

Heat Transfer.

When two bodies of unequal temperatures are near each other, there is a constant tendency to equalize the temperature by a transfer of heat from the hotter body to the colder body. Without such temperature difference no heat transfer between two bodies can be effected. *Thus, the impelling force in heat transfer is temperature difference.*

This heat transfer takes place in three ways: by *radiation,* by *conduction* and by *convection.*

Radiation of Heat.—A certain amount of heat which is given off by luminous and hot bodies follows the straight-line law for propagation of light. The amount of heat absorbed by a body exposed to such radiant heat has been found to depend upon the condition of the surface of the body and the difference of the fourth powers of the absolute temperatures of the radiating and absorbing bodies. Black bodies absorb a relatively larger proportion of heat than bodies having surfaces tending to reflect such heat.

The effect of radiant heat in boiler furnaces is to increase considerably the rate of absorption of the heating surfaces exposed to the action of the radiant heat given off by the fuel bed and by such refractory brick surfaces as are heated to incandescence. The luminous particles in the gases give off a comparatively small quantity of radiant heat.

Radiant heat should not be confused with what has been termed "radiation" from hot surfaces such as hot cylinders, boilers, casings

and steam pipes which are not well lagged. Such radiation is in reality a loss by convection to the surrounding particles of air, since the proportion of heat lost by true *radiation* is small unless the temperature difference is high.

Conduction of Heat.—The transfer of heat by conduction may be between the particles of the same body or between particles of different bodies in contact. The heat in this case flows from particle to particle. In the case of the transfer of heat between particles of the same body, the transfer is said to be by *internal conduction.* The *rate of heat transfer* will depend upon the thermal conductivities of the substances. The thermal conductivities of various substances, liquid, solid and gaseous, have been determined by experiment and are tabulated below.

Substance.	B.T.U.'s per hour per square foot per degree F. per inch thick.	
Iron	443	at 82° F.
Steel	279.5	at 82° F.
Zinc	443	at 59° F.
Copper	2080	at 32° F.
Water	3.6	at 65° F.
Alcohol	1.4	at 65° F.
Petroleum	1.03	at 65° F.
Air	.165	at 32° F.
Nitrogen	.152	at 32° F.
Oxygen	.163	at 32° F.

It will be noted that the values for gases are very much lower than those for solids, and this fact has an extremely important bearing on the design and arrangement of heating surfaces for maximum efficiency.

The resistance of gases to the transfer of heat by conduction makes it very difficult to effect a transfer of heat from a metal to a gas, or *vice versa,* where the gases are not in motion. This principle has been employed in lagging boilers by means of an air space between the inner and outer casings.

Convection of Heat.—When the transfer of heat occurs between particles of gases or fluids, the whole mass is heated largely by convection; that is, the particles nearest the source of heat become heated first and rise through the mass on account of their lesser density, being replaced by colder particles of greater density, which in turn become heated and rise until the whole mass is at the same temperature. The currents set up in this manner are called *con-*

vection currents and greatly accelerate the transmission of heat through gases and liquids. It is for this reason that hydrokineters are installed on Scotch boilers to increase the convection currents and thereby increase the rate at which the water in the boiler becomes heated.

Thus the necessity for the circulation of water in any boiler is at once apparent, but the greater necessity for a rapid flow of hot gases across the cooler heating surfaces of boilers has for many years been overlooked.

Transmission of Heat into Heating Surfaces.—When the hot gases resulting from the combustion of coal or oil fuel pass along the heating surfaces of a boiler, a thin film of gas adheres to the surface and gives up some of its heat to the metal. This cool film of gas, however, remains in contact with the metal and prevents the hotter gases from coming in contact with the heating surface and transmitting their heat to the metal. Since the resistance of this thin film of gas to the transmission of heat by conduction is very high, it is evident that the greatest proportion of heat losses from hot gases to heating surfaces is due to this gas film. The film can be removed only by increased circulation of the gases over the heating surface. The increased speed results in a scouring action which removes to some extent the cool film.

In like manner, the water on the other side of the tubes, in passing, leaves a thin film adhering to the tubes, which offers a high resistance to the flow of heat from the tubes to the water. This film of water, however, would offer only about one-tenth as much resistance to the flow of heat as would a gas film of equal thickness. It is evident, therefore, from a glance at the table of thermal conductivities (page 172), that the *controlling resistance to heat absorption* lies on the gas side of the metal, and before any considerable improvement can be made in heating surface efficiency by increased circulation of water in the boiler, the controlling resistance (*i. e.*, resistance of the gas film) must be reduced.

The flow of heat from the gases to the water is therefore as follows: From the gases to the gas film by convection; through the gas film to the metal by conduction; through the metal by conduction; from the metal to the water film by conduction, and from the water film to the water by convection.

If the tubes are covered with soot deposits on the gas side or with scale on the water side, the resistance to the flow of heat by conduc-

tion will be still further increased. Hence, the necessity for keeping the tubes free from soot and scale is apparent.

The effect of scale, or deposits of insoluble substances on the water side of the tubes has a still further effect. The metal of the tube takes the temperature of the medium opposite to the controlling resistance, so that, in general, with clean tubes, it will take the temperature of the water. If, however, a thick scale, having a high thermal resistance, is allowed to accumulate on the water side, the controlling resistance may pass to the water side and the tube will take the temperature of the gases. This will cause severe overheating of the metal, which may result in burning out the tube.

Evaporation.

Formation of Steam.—When fires are started in the furnaces of a boiler, with the safety-valves open, the particles of water in contact with the heating surfaces become heated, expand, and rise to the surface, being replaced by the cooler particles from above. As the heating, which we can measure practically by a thermometer in the water, goes on, the whole mass is raised in temperature until the boiler is full of boiling water, giving off vapor or steam when 212° F. is reached. This point, called the *boiling point,* will always correspond to this temperature when the water is under atmospheric pressure, 14.7 pounds to the square inch. If, under these conditions, the application of heat is continued, the thermometer remains stationary at 212° F. until all of the water has been evaporated into steam of atmospheric pressure and a temperature of 212° F. It is apparent, therefore, that a large amount of heat has been absorbed by the water in changing it from liquid into vapor or steam.

If the safety-valves are closed when the boiling point is reached, there is, at that instant, a boiler full of water at a temperature of 212° F. and under a pressure of 14.7 pounds per square inch, and the steam gage shows the pointer at zero, or no pressure by gage.

The safety-valves being closed, the thermometer will show a gradual increase in the temperature of the water as the absorption of heat from the hot gases continues. If the steam gage is now observed, it will be seen that the pointer has left the zero mark and is rising, showing that there is a pressure in the boiler. This pressure is caused by confining the steam as it is formed in the steam space of the boiler, and, as we have started with the atmospheric pressure in it, the reading of the pressure, as shown by the

steam gage, must be increased by 14.7 pounds to give the total, or absolute pressure.

Now, suppose that when the absolute pressure has reached 80 pounds, or 65.3 pounds by gage (at which pressure the temperature is 312° F.), the stop-valves are opened and the engine is started and run at such speed as to keep the pressure in the boiler constant. Under these conditions it is found that while heat is being absorbed continuously for the production of steam of 80 pounds pressure, the temperature of the water remains at 312° F., instead of at 212° F., as when the pressure was that of the atmosphere only.

Again, if the conditions are fixed to produce steam constantly at 160 pounds absolute, or 145.3 pounds by gage, the temperature of the water remains at 363.6° F.

Boiling Point.—From the above examples it is seen that the temperature at which the water is converted into steam, or its boiling point, does not remain constant, but that it bears some relation to the pressure. If the process had been started with a pressure of 80 pounds absolute on the surface of the water, no boiling would have taken place until the temperature of the water had been raised to 312° F. There is, then, a certain boiling point for each pressure, which increases with the pressure. The relation between the temperature and the pressure has been determined experimentally, and is given in Table I, at the end of this book.

As the boiling point, or temperature of the steam, and other data are needed usually for a certain pressure as read on the steam gage, it must not be forgotten that the temperature depends upon the absolute pressure, or the pressure above a perfect vacuum. Tables I and II are made out for absolute pressures only, so that, when using them, 14.7 pounds must be added to the reading of the steam gage.

In Table II the data have been arranged for pressures below the atmosphere, in inches of mercury.

The boiling point of water is increased by salts dissolved in it, as in sea water, but not by bodies in mechanical suspension only, as sand in river water. For sea water, which contains about 1/32 part of solid matter, the boiling point is 213.2° F. under atmospheric pressure; and this is raised as the proportion of salt or dissolved solid matter increases, so that, with a concentration of 4/32, the boiling point, under atmospheric pressure, would be about 217° F. But it has been proved by experiment that the steam produced from any

saline solution is that of pure water (this fact being taken advantage of in distilling of fresh water), and also that the temperature of the steam formed at higher pressures is the same as that of steam formed from fresh water at the same pressure.

Sensible Heat.—From the explanation of the formation of steam previously given, it is apparent that not all of the heat expended in raising the temperature of the water to the boiling point, and in evaporating it at any pressure, is recorded by the thermometer as rise of temperature. The quantity of heat which the thermometer measures is called the *sensible* heat. The thermometer does not measure the exact amount of sensible heat, on account of the variation in the specific heat of water with change of temperature. The exact value of the sensible heat of water may be picked out from the steam tables for any required temperature.

Latent Heat.—When water is allowed to boil at any pressure, any further addition of heat is expended in changing the water to steam, *without increase of temperature* until all the water present has been converted into steam. The heat required to change the "state" of a unit weight (1 pound) of a body is called the *latent heat* of the substance. This latent heat, in the case of steam, consists of two parts, called respectively the *external* and *internal* latent heat. The internal latent heat is that expended in overcoming the mutual attraction of the molecules of water, which resist change of state to steam, whereas the external latent heat is equivalent to the work done in changing the volume at constant pressure during the transformation to steam. The external latent heat is measured as follows:

$$\text{External latent heat} = \frac{p}{J}(v - v'),$$

where p = absolute pressure in pounds per square foot, v = specific volume of saturated steam, v' = volume of 1 pound of water, and J = Joule's equivalent = 778. In the steam tables this term is denoted by

$$144Apv = L - \rho,$$

where ρ is internal latent heat, and $A = \frac{1}{J}$. (v' = the volume of 1 pound of water, which is negligible in comparison with the volume of steam.) Then the total latent heat of vaporization of steam at any pressure and corresponding temperature is the sum of the *internal* and *external* latent heat. The latent heat of vaporization

of steam decreases with increase of temperature and pressure. Therefore, all the latent heat which goes to change the water into steam, while not evidenced by a change of temperature during the process, is still latent in the steam as potential thermal energy, and is capable of being transformed into mechanical energy exactly as potential mechanical energy may be transformed into kinetic mechanical energy.

Total Heat of Steam.—The total heat of steam at any definite pressure and temperature is the number of B. T. U. necessary to raise a quantity of water from 32° F. to the temperature required, and to change it to steam at that temperature and pressure. When total heat is referred to in engineering, it means the total heat in a quantity of steam above the arbitrary zero, which is taken at 32° F. It is expressed by the equation formula

$$H=L+S,$$

where L is latent heat and S is sensible heat, and is the sum of latent and sensible heats at that temperature. Thus the total heat of 10 pounds of dry steam at 212° F. equals 10 times the total heat of 1 pound of dry steam at 212° F. The numerical value of the total heat of 1 pound of steam at any given temperature and pressure may be obtained from the steam tables, or may be computed from the following empirical formula when no steam tables are available:

$$\begin{aligned} H &= \text{total heat of 1 pound of steam} \\ &= 1150.3+.3745(t-212)-.00055(t-212)^2. \end{aligned}$$

From an inspection of the steam tables, and the above formula, it is evident that the total heat of a pound of steam increases with an increase of temperature.

Saturated Steam.—When a quantity of water is allowed to boil and steam is formed in contact with the water, this steam is normally dry and contains no particles of water held in suspension with it. Steam in this condition is said to be *saturated,* and has a definite volume and pressure at any given temperature. If any heat is abstracted from the steam while it is in this state, some of it will condense. Any increase in pressure will likewise cause a partial condensation of the steam. If the pressure is reduced, some of the water with which it is in contact will flash into steam. At a given temperature, saturated steam has the greatest density and pressure possible to remain a dry vapor.

Wet Steam.—If, for any reason, such as loss of heat from saturated steam, some of the steam is condensed to water and these particles of water remain suspended in the steam, the resulting mixture is called *wet steam.* Wet steam is sometimes formed in a boiler by the violent ebullition of water, causing some of the particles to be carried off in the steam. In well-designed boilers, the quantity of this entrained water rarely exceeds 1%. In a definite weight of wet steam, the percentage of dry steam in the total quantity of moisture and dry steam is termed the *quality of the steam.* Thus when a pound of water is converted into wet steam of quality .98 there is by weight 98% of dry steam and 2% of moisture in the steam.

Total Heat of Wet Steam.—Let Q represent the quality of the steam. Then, from one pound of water, Q parts will be changed to steam and $(1-Q)$ parts will remain water. Therefore, the total heat of the steam will equal

$$H=Q(L+S)+(1-Q)S=QL+S,$$

where L=latent heat and S=sensible heat, or heat of the liquid, for the given temperature.

Example: Find H, L and S for dry steam, when the steam gage shows 135.3 pounds, the temperature of the feed water being 32° F.

From the table, $L=863.2$, $S=330.2$, and H therefore$=863.2+330.2=1193.4$ B. T. U.

Now suppose that, instead of dry steam, the quality of the steam is .97. Then

$$H=.97L+S=.97\times 863.2+330.2=1167.5 \text{ B. T. U.}$$

Superheated Steam.—If a quantity of steam is removed from contact with the water from which it was generated, and additional heat is put into it, the result will be superheated steam.

If the volume of steam is kept constant by confining it in a closed vessel, the pressure and temperature will rise with the addition of heat; whereas, if the pressure is kept constant, the volume and temperature will both become greater than the volume and temperature at saturation. The amount of increase in temperature above the temperature of saturation at a given pressure is the number of degrees of superheat.

Superheated steam approaches the condition of a perfect gas, particularly with high degrees of superheat, and therefore follows very nearly Boyle's Law for variations of temperature, pressure and volume.

Boyle's Law: "As long as its temperature remains the same, the pressure of a quantity of gas is inversely proportional to its volume."

The specific heat of superheated steam varies with the temperature, and, in general, has an average value of nearly .48 for *low* degrees of superheat. This value (.48) is close enough for rough calculations where only moderate temperature and low degrees of superheat are used. The total heat of superheated steam is given by the following equation:

$$H'' = H + C'_p(T - t),$$

where

H'' = total heat of superheated steam,

H = total heat of dry (saturated) steam at temperature t.

$C'p$ = mean specific heat, at constant pressure of superheated steam for the temperature range.

T = temperature of the superheated steam.

t = temperature of saturated steam at pressure p.

($C'p$ may be taken roughly at .48.)

Heat Required to Produce Steam from Feed Temperature.—In Tables I and II the calculations are based on a temperature of 32° F. for the feed water. But, in practice, this temperature is always higher, and therefore less heat will be required to raise the feed water from its entering temperature to that corresponding to the pressure.

Example: How many thermal units are required to produce steam at a pressure of 135.3 pounds by gage, the feed water being admitted at 160° F.? Quality of steam .97.

As before, S, or the heat of the water corresponding to a pressure of 150 pounds absolute, is 330.2. But the heat of the feed water S' corresponding to a temperature of 160° F. is 127.86 B. T. U. Therefore, to raise the feed water to the boiling point, $330.2 - 127.86 = 202.34$ B. T. U. are required. $S - S'$ may be taken as the new value of S. QL is $.97 \times 863.2 = 837.3$.

Therefore, there will be required under these conditions only $837.3 + 202.34 = 1039.64$ B. T. U.

Actual and Equivalent Evaporation.—Taking the heating value of one pound of average steaming coal as 14,162 B. T. U., and assuming that the boiler transfers .68 of the heat of the coal to the water, each pound of coal burned gives $14{,}162 \times .68 = 9630.2$ units to the water. But, to convert one pound of water from 160° F. into steam of quality .97 and a pressure of 135.3 pounds by gage, only

1039.64 units are required. Therefore, $9630.2 \div 1039.64 = 9.26$ pounds of water were vaporized by each pound of this coal under the above conditions, or the actual evaporation is 9.26 pounds.

The theoretical evaporative power of the fuel, from and at 212° F., is 14.59 pounds; and, as the efficiency of the boiler is ,68, the real evaporative power of the fuel, from and at 212° F., is $14.59 \times .68 = 9.92$ pounds. This result would have been obtained directly by dividing 9630.2, the heat units absorbed by the water, by 970.4, the heat units required to convert 1 pound of water from a feed temperature of 212° F. into dry steam of the same temperature.*

That is, the evaporation of 9.26 pounds of water under the actual conditions is equivalent to the evaporation of 9.92 pounds from and at 212° F.; or, using the usual expression, the equivalent evaporation from and at 212° F. is 9.92 pounds.

Factor of Evaporation.—This is the ratio of the number of heat units in 1 pound of steam at the given pressure, and calculated from the temperature t of the feed water, to the number required to vaporize 1 pound of water into dry steam from and at 212° F.; or,

$$f = \frac{H - S'}{970.4} = \frac{QL + S - S'}{970.4},$$

S' being the heat units in the feed water at the temperature t.

For the above example, under total heat of wet steam, $1193.2 - 127.86 \div 970.4 = 1.098$ is the factor of evaporation.

Tables are published giving the factors of evaporation for various steam pressures and temperatures of feed water. But, as these assume that the steam produced in every case is dry, the method given above must be followed when Q is other than unity, or, if the factors are used, Q must be corrected as will be explained under "Boiler Tests."

The various steps in the transference of the heat energy of the fuel to the steam have been shown, and the energy of this steam is now ready to do useful work in the various engines on board.

* The latest authoritative steam tables (Marks and Davis) give this value as 970.4.

CHAPTER VII.

COMBUSTION.

Combustion, in its broadest sense, is any chemical act that is accompanied by the evolution of heat. Ordinarily, it is restricted in meaning to the chemical union of other substances with oxygen, resulting in the production of heat.

A combustible substance is one which, when raised to its temperature of ignition, combines readily with the oxygen in the air, producing heat.

The Chemistry of Fuel and Combustion.

The five principal elements found in ordinary fuel are:

	Symbol.	Approximate atomic weight.
Carbon	C	12
Hydrogen	H	1
Oxygen	O	16
Nitrogen	N	14
Sulphur	S	32

The *atomic weights* are the relative proportions, by *weight*, in which the elements combine with each other to form definite chemical compounds. Thus,

$$2H + O = H_2O,$$

or

$$2 \text{ lbs } H + 16 \text{ lbs. } O = 18 \text{ lbs. } H_2O = \text{water.}$$

Similarly,

$$12 \text{ lbs. } C + 16 \text{ lbs. } O = 28 \text{ lbs. } CO = \text{carbon monoxide,}$$
$$12 \text{ lbs. } C + 32 \text{ lbs. } O = 44 \text{ lbs. } CO_2 = \text{carbon dioxide,}$$
$$12 \text{ lbs. } C + 4 \text{ lbs. } H = 16 \text{ lbs. } CH_4 = \text{methane (marsh gas).}$$

Composition of Air.

Ordinary air is composed principally of oxygen and nitrogen with varying amounts of water vapor held in suspension. These constituents do not exist in air as a chemical compound, but simply as a mechanical mixture. Therefore, the oxygen present in the air is free to combine with other elements to support combustion.

For practical purposes the composition of air may be taken as 77% nitrogen and 23% oxygen by weight, and 79% nitrogen and 21% oxygen by volume.

The amount of moisture (or water vapor) in the air is determined by the *relative humidity* of the atmosphere. This relative humidity is determined by tables in which the arguments are the readings of the wet- and dry-bulb thermometer, or by instruments constructed to give the temperature of the dew-point for any existing atmospheric conditions.

Humidity is the ratio of the moisture contained in the air at a given temperature to the amount it is capable of containing at that temperature when saturated. It is expressed as a percentage.

General Characteristics of the Principal Elements in Combustibles.

Hydrogen.—Hydrogen is a very light combustible gas. When it combines with oxygen, the result is the liberation of 62,032 B. T. U. per pound of hydrogen burned. The result of this combustion is the formation of H_2O in the form of water vapor or steam, some of the heat units resulting from combustion going to change the water to steam. This results in a loss of 970.4 B. T. U. for every pound of H_2O thus generated at atmospheric pressure. This apparent loss of heat gives rise to the double heating value of hydrogen as usually tabulated; viz., the higher and the lower.

Oxygen.—Oxygen is 16 times as heavy as hydrogen and is the universal supporter of combustion. Without oxygen there can be no combustion.

Nitrogen.—Nitrogen is an invisible gas, 14 times as heavy as hydrogen. It has so little chemical affinity for other elements that it will not combine with them easily by the ordinary chemical methods. It is the diluent of oxygen in the air, restraining the activity of the oxygen and causing combustion and corrosion to be less rapid than in pure oxygen.

Carbon.—Carbon exists (a) in the pure state, in diamond, coal and graphite; (b) combined with hydrogen, in oils, tars and gases; (c) combined with hydrogen and oxygen, in the whole range of vegetable products. It is the principal constituent of coal and of most other fuels, whether in the solid, in the liquid, or in the gaseous form.

Sulphur.—A trace of sulphur is found in most coals, varying in amounts from .10% to about 3.0%. It has a low heating value (4050), and has the further disadvantage of combining readily with any

moisture, forming sulphuric acid, which is injurious to the boiler material. Coal relatively high in sulphur is not accepted by the Navy for steaming coal.

Heating Value of Combustibles.

In general, chemical reactions are accompanied by the absorption or evolution of heat. When a combustible unites with oxygen, the process is characterized by the evolution of a considerable quantity of heat. The heat thus evolved per unit weight (pound) of combustible is called the *heating value* of the substance. Hydrogen, and compounds containing hydrogen, have two heating values, called respectively the *higher* and the *lower*. This is due to the fact that the result of the union of hydrogen and oxygen may be either water or steam. If the product is steam, then the heat necessary to keep it in the form of a vapor is not set free and the lower heating value must be used. If, however, the vapor condenses, the heat of vaporization and some of the sensible heat of the liquid is recovered, yielding the higher heating value.

The following table gives the heating values of various substances.

HEATING VALUES OF 1 POUND OF VARIOUS PURE SUBSTANCES BURNED IN OXYGEN.

Substance.	Burned to	B.T.U. generated	Authority.
Hydrogen	Liquid water (H_2O)	62032	Favre & Silbermann.
Hydrogen	Liquid water (H_2O)	61816	Thomsen.
C (wood charcoal)	CO_2	14544	Favre & Silbermann.
C coal	CO_2	14647	Bertholot.
C (diamond)	CO_2	14146	Bertholot.
C (black diamond)	CO_2	14150	Bertholot.
C (graphite)	CO_2	14222	Bertholot.
C	CO	4451	Favre & Silbermann.
CO, per unit of CO	CO_2	4325	Favre & Silbermann.
CO, per unit of CO	CO_2	4293	Thomsen.
CO, per unit of C	CO_2	10093	Favre & Silbermann.
CH_4	CO_2 and H_2O	23513	Favre & Silbermann.
CH_4	CO_2 and H_2O	23616	Thomsen.
C_2H_4	CO_2 and H_2O	21523	Thomsen.
C_2H_4	CO_2 and H_2O	21344	Favre & Silbermann.
C_2H_2	CO_2 and H_2O	18196	Calculated.
C_6H_6 benzole gas	CO_2 and H_2O	17847	Favre & Silbermann.
C_6H_6 benzole gas	CO_2 and H_2O	18184	Thomsen.
Sulphur	SO_2	4050	N. W. Lord.

The heating value of a mixture is determined from the heating values of the several constituents. If the *percentage by weight* of the

constituents is denoted by M_1, M_2, M_3, ..., and their corresponding heating values per pound by H_1, H_2, H_3, ..., the heating value of the mixture H_m may be determined as follows:

$$(M_1+M_2+M_3+\ldots.)H_m=M_1H_1+M_2H_2+M_3H_3+\ldots.;$$

$$\therefore H_m=\frac{\Sigma M_nH_n}{M},$$

where $M=100\%=100$.

Example: Required the heating value of the fuel having the constituents by weight as given below:

Constituent.	% by weight.	H.	MH.
H_2	4.8	62032	297753.6
C	83.5	14544	1214424.0
O_2	4.2	neglected	
N	1.3	non-combustible	
S	.7	4050	2835.0
Ash	5.5	non-combustible	

$$\Sigma HM=1515012.6$$

$$\therefore H_m=15150 \text{ B. T. U.}$$

This gives a slightly higher value than is found by experiment.

Dulong's Formula.—Dulong's Formula is derived in the manner shown above, but assumes that the oxygen in the fuel has already combined with the hydrogen in the fuel and the heat so generated lost; therefore the term $(\mathrm{H}-\frac{\mathrm{O}}{8})$ appears in the formula, since the combining proportions of H and O are as 1 to 8 by weight.

The formula is as follows:

$$\text{Heat value in B. T. U.}=\frac{1}{100}[14{,}600\,\mathrm{C}+62{,}000(\mathrm{H}-\frac{\mathrm{O}}{8})],$$

where C, H and O are the percentages by weight of carbon, hydrogen and oxygen in the fuel as determined by analysis.

Air for Combustion.

The oxygen required for the complete combustion of a given fuel is determined from the equation of its reaction. For example:

$$\mathrm{C}+2\mathrm{O}=\mathrm{CO_2};$$

or, taking the atomic weights,

$$12 \text{ lbs. C}+32 \text{ lbs. O}=44 \text{ lbs. } \mathrm{CO_2},$$

$$1 \text{ lb. C}+\frac{32}{12}\text{ lbs. O}=\frac{44}{12}\text{ lbs. } \mathrm{CO_2},$$

$$\frac{9}{10}\text{ lb. C}+\frac{32}{12}\times\frac{9}{10}\text{ lbs. O}=\frac{44}{12}\times\frac{9}{10}\text{ lbs. } \mathrm{CO_2}.$$

To obtain 1 pound of oxygen, $\frac{1}{.23}$ pounds of air are necessary, since each pound of air contains .23 oxygen by weight. Therefore, in the foregoing example:

.9 lb. C requires $\frac{32}{12} \times \frac{9}{10} \times \frac{1}{.23}$ lbs. of *air* for complete combustion.

If the composition by weight of a fuel is obtained from the ultimate analysis, the air required for complete combustion may be calculated as indicated below for a sample of Pocahontas coal:

Constituent.	% by weight.	
C	83.5	
H_2	4.8	
O_2	4.2	
S_2	0.7	Generally neglected in practice.
N_2	1.3	non-combustible.
Ash	5.5	non-combustible.
	100.0	

Then:

	Lbs. air.
.835 lb. C requires $\frac{32}{12} \times \frac{.835}{.23} =$	9.68
.048 lb. H_2 requires $\frac{.048}{.23} \times 8 =$	1.67
	11.35

The above method does not take into account the oxygen in the fuel to start with. This is generally considered as combining with the H in the coal, and the H value is reduced by $\frac{O}{8}$, since the combining proportion of H and O is as 1 to 8. Then the corrected value of H is

$$.048 - \frac{.042}{8} = .048 - .0053 = .0427,$$

and the correct solution of the problem is:

	Lbs. air.
.835 lb. C requires $\frac{32}{12} \times \frac{.835}{.23} =$	9.68
.0427 lb. H requires $\frac{.0427}{.23} \times 8 =$	1.485
	11.165

Therefore, one pound of the fuel having the analysis given above requires 11.165 pounds of air for its complete combustion. In practice, however, coal can never be burned completely without more air than is theoretically required, the excess per cent being termed the *excess air*.

Ultimate Analysis.

The **ultimate analysis** of a coal is the quantitative chemical analysis of a representative sample of the coal. This analysis should be performed only by an expert chemist, as it requires great skill. The ultimate analysis of any coal mined in the United States may be obtained from the tables issued by the Bureau of Mines.

The coal most commonly used in the United States Navy is semi-bituminous coal. The ultimate chemical analysis of this coal shows its constituents to be carbon, hydrogen, oxygen, sulphur, nitrogen, and ash. The ash is composed of non-combustible solids, including slate, etc., and has the particular advantage of not being readily fused at high furnace temperatures. This coal is therefore relatively free from a tendency to clinker unless fires are carried very thick.

Although the ultimate analysis will determine the percentage of each of the constituents of the coal, nothing is definitely known regarding the manner in which these constituents are combined among themselves. It is probable, however, that some very complex chemical compounds exist in the coal, some of which are driven off in gaseous form when the coal is heated. The gases thus formed are termed *volatiles*. The amount of volatile matter distilled from the coal will depend upon the temperature at which distillation occurs. In general, the higher the temperature the greater will be the amount of volatiles and the more complex will be the chemical nature of the products. The volatile matter from semi-bituminous coal consists of hydrocarbons, ammonia and coal tar products. The lighter hydrocarbons such as methane, CH_4, burn readily. The heavier distillates resulting from rapid heating at a high temperature are more complex, have a high ignition temperature, and are, therefore, much more difficult to burn.

The residue after the volatiles are driven off consists of what is termed *fixed carbon* and ash. This fixed carbon burns to CO and CO_2, the relative proportions of each depending upon the thickness of the fuel bed, the temperature, and the amount of air supplied.

Proximate Analysis.

The **proximate analysis** is used to determine the percentage of moisture, volatile matter, fixed carbon and ash in the coal. It is carried out as follows, viz.:

(1) From a weighed sample, say a gram of coal, the moisture is first driven off by heating it to a temperature of from 250° to 300° F. for a given time. The sample is then quickly reweighed, the ratio, loss of weight to the original weight, being the percentage of moisture.

(2) The volatile matter is then driven off by heating the sample in a closed crucible to a red heat for a short time. It is then reweighed and the percentage of loss of weight is the percentage of volatile matter distilled off.

(3) The carbon is burned out of the remaining coke by keeping it at white heat with a plentiful supply of air until nothing is left but ash. The ash is weighed and the percentage of fixed carbon and ash thereby determined.

It must be remembered, however, that the amount and quality of the volatiles driven off in the proximate analysis are relative only, and do not necessarily determine the conditions existing in a hand-fired furnace where the coal is subjected to destructive distillation at high temperatures.

Classification of Coal.

Coals are classified according to the relative percentages of carbon and volatile matter contained in the combustible portions, anthracite showing the lowest percentage, and bituminous the highest percentage, of volatile matter on analysis.

Composition of Coal.

CHEMICAL COMPOSITION OF VARIOUS STEAMING COALS AND LIQUID FUELS, THEIR HEATING VALUES, AND VOLUME OCCUPIED BY ONE TON.

Name of fuel and country from which obtained.	Ultimate analysis.						Proximate analysis.				Heating value of one pound of dry fuel in B. T. U.	Number of cubic feet occupied by one ton of 2240 pounds of fuel.
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Fixed carbon.	Volatile matter.	Ash.	Moisture.		
Anthr. and Semi-Anthr.												
Pennsylvania, av..........Am.	....	....	....	....	....	.....	88.5	4.0	6.3	1.2	13,100	42.4
Lehigh, Pa.............. "	85.7	2.8	2.9	.8	.5	7.3	86.5	4.3	7.2	2.0	......	....
Drifton, Pa.............. "	87.7	2.6	2.8	1.0	.4	6.0	89.1	3.6	5.9	1.4	13,722	....
Nixon's Navigation......Wales	87.7	4.0	2.5		5.8		....	....	....	....	15,010	....
Powell's Duffryn....... "	88.3	4.6	.6	1.4	1.8	3.3	....	....	....	....	16,108	....
Isère....................France	90.0	1.5	1.5		7.0		....	....	....	....	13,782	40.4
Semi-Bituminous.												
Pocahontas, W. Va....... Am.	83.5	4.8	4.2	1.8	.7	5.5	77.3	17.1	5.1	.5	14,578	
New River, W. Va........ "	83.6	4.7	4.5	1.6	.7	4.9	72.7	21.7	4.8	.8	14,488	44.1
George's Creek, Md....... "	81.0	4.9	4.6	2.2	.7	6.6	74.3	18.5	6.6	.6	13,987	av.
Clearfield, Pa............ "	80.2	5.1	4.7	1.4	.9	7.7	73.2	18.8	7.6	.4	......	Am.
Cardiff, av..............Wales	88.8	4.8	4.1	1.0	1.4	4.9	80.	17.	3.	....	......	42.7?
Newcastle................Engl.	82.4	5.5	6.3	1.6	1.3	2.9	....	....	....	....	14,820	45.3
Bituminous.												
Pittsburgh steaming......Am.	76.5	5.2	8.1	1.4	1.2	7.6	59.1	32.0	7.5	1.4	13,280	....
Pratt seam, Ala.......... "	....	....	....	....	....	......	63.8	31.5	3.5	1.2	14,580	....
Washington State, av..... "	....	....	....	....	....	......	57.7	32.8	8.3	1.2	......	45.5
Br. Columbia, av..............	....	....	....	....	....	......	56.5	33.9	8.1	1.3	......	
Scotch, av.............	78.5	5.6	9.7	1.0	1.1	4.1	....	....	....	....	12,870	45.0
Miike....................Japan	75.0	5.8	?	1.1	3.2	12.0?	....	....	....	....	......	45.6
Chilean, av....................	63.6	5.4	14.8	.8	2.5	12.9	....	....	....	....	11,030	46.5?
Batan Island..............P. I.	....	....	....	....	.5	......	45.	40.	5.5	9.	......	....
Patent Fuel.												
British, av.....................	83.4	5.0	2.8	1.1	1.3	6.4	....	....	....	....	15,000	34.4
Warlich's ....Engl.	90.0	5.6	....	....	1.6	2.8?	....	....	....	....	16,495	....
French, av......................	....	....	....	....	....	8.3	....	....	....	....	15,000	34.5
							Sp. Gr.	Flash.	Fire.			
Liquid Fuel.												
Pennsylvania, kerosene........	85.0	13.5	1.5	....	....	......	.784	120°	150°	....	20,156	
Pratt's fuel oil, Pa............	....	....	....	....	....	......	.852	200	268	....	19,980	
Eagle fuel oil, Pa.	....	....	....	....	....	......	.849	249	296	....	19,742	34–36.
Beaumont, Tex., distilled.....	83.3	12.9	3.8	....	.5	......	.926	216	240	....	19,480	
Kern River, Cal., distilled....	84.4	11.0	3.4	.6	.6	......	.962	228	258	....	18,806	
Astatki, Baku,* Russ	85.0	13.7	1.3	....	....	......	.940	....	....	2.0	18,560	35.0
Borneo, crude.	83.4	10.3	6.3	(incl. impurities)			.960	....	....	12.0	18,000	av.
Burma, refuse*.................	86.0	12.4	1.6	....	....		....	....	....	....	18,860	

* After sulphur and other impurities have been removed.

Combustion of Coal in Furnaces.

When a fresh charge of green coal is thrown on the incandescent fuel bed, the first process is the evaporation of the moisture in the coal. This is essentially a cooling process, since heat must be absorbed by the moisture in changing its state from water to steam, and such heat is abstracted from that evolved by the incandescent fuel. After the moisture has been driven off, the distillation of volatiles begins, and since the process occurs rapidly and at a high temperature, the volatiles consist of the heavy hydrocarbons and coal tar products. These volatiles require a large amount of air and a high temperature for complete combustion, but in hand-fired furnaces the fresh charge of coal falls between the interstices of the incandescent fuel bed, blocking the supply of air at the very time it is most needed. Therefore, volatile matter combined with the CO and CO_2 from the incandescent fuel may travel through the combustion space without coming in contact with sufficient air for combustion until after it has been chilled below the ignition temperature by the relatively cooler heating surfaces. The unburned coal tar globules and carbon particles are deposited upon the heating surfaces as soot or pass out through the uptake as a dense smoke, giving visible evidence of poor furnace conditions.

The distillation of the heavier volatiles takes ordinarily about three minutes, after which the residue burns as fixed carbon, distilling off only a slight amount of volatile matter.

When air first comes in contact with this incandescent carbon, the oxygen unites with it to form CO_2. If the fuel bed is thick, however, and the CO_2 remains for a relatively long time at a high temperature in contact with the incandescent carbon, the CO_2 will unite with more carbon to form CO. The formation of CO is particularly liable to occur if any moisture is present in the air, such moisture reacting with the incandescent carbon; thus:

$$H_2O + C = CO + H_2.$$

The formation of CO as here described requires heat to bring about the reaction, and thus cools the furnace. The presence of any CO is undesirable, as its heating value is only about 30% of that of CO_2.

The CO thus mixed with CO_2 in the combustion space of the furnace may be reconverted into CO_2 by bringing its particles into intimate contact with air at a sufficiently high temperature.

It has been found, however, that excess air admitted above the grate will not assist in the combustion of the gases unless some special mixing device is employed. Experiments show that streams of combustible gas and air will travel side by side without burning except where they actually make contact, unless some baffling arrangement forces them to mix. Up to the present time such baffles have not been a practical success on account of the resulting high temperatures which fuse ordinary fire brick. The excess air admitted over the grate for the purpose of completely burning the volatiles serves only to chill the gases and results in a loss of efficiency.

The ash which results from the combustion of coal falls through the grate bars into the ash pit, or fuses, forming *clinkers*. Clinkers are particularly liable to form with coals having an ash which fuses at temperatures around 2400° F., and when heavy fires are carried. The ash of some coals is more liable to fuse than others, but the tendency of an ash to fuse cannot be determined by a chemical analysis of the constituents. The tendency of an ash to clinker may make all the difference between an excellent steaming coal and a poor one.

Furnace Temperatures.—From the above, it is apparent that a large proportion of the heating value of the fuel is due to the volatile matter of the coal, and the boiler furnace may be regarded as a gas producer. The problem then becomes one of burning these gases completely with the minimum excess air.

Theoretically furnace temperatures might be computed by the following formula, viz.:

$T =$ rise in temperature (t) + temperature of air in fire room (t_1), or

$$T = t + t_1 = \frac{\text{B. T. U. generated by fuel}}{\text{weight of gases} \times \text{specific heat of gases}}.$$

Such computations are of no practical value, since the theoretical temperatures are generally about twice as large as those actually attained, for two reasons: (1) Heat is being absorbed by radiation and convection during the process of combustion; (2) the dissociation temperatures of some gases are reached, the heat going to break down the chemical compounds without further increase of temperature.

In practice, furnace temperatures with semi-bituminous coals vary from 2000° to about 3000° F., being lowest right after a fresh charge is fired.

Furnace Efficiency.—The *efficiency* of the furnace is the ratio of the heat actually generated to the heat in the combustible (fuel free from ash). There is no practical method of determining the amount of heat actually generated, since the temperature of the gases is not necessarily a function of the furnace efficiency, and therefore such determination must be made indirectly.

The furnace losses are:

(1) Loss due to incomplete combustion of fuel.
(2) Loss due to radiation and conduction.
(3) Loss due to excess air.
(4) Loss due to unburned combustible falling through the grate.
(5) Loss due to moisture in coal and air, requiring a certain amount of heat to convert the water into steam.

The losses due to incomplete combustion may be approximated from the analysis of flue gas, but it must be remembered that the volumetric analysis does not (except in laboratory work) show the loss due to unburned hydrocarbons, etc. It has been found, however, that when, upon analysis, CO is present in a flue gas, it is generally accompanied by some CH_4, C_2H_{10}, etc.; therefore relatively large amounts of CO (over 0.1%) should be regarded as indicating poor furnace conditions.

Losses due to radiation and conduction generally amount to about 4% of the total heat balance in the B. & W. boiler. (See Appendix.)

Losses due to excess air may be serious when it exceeds that necessary for complete combustion, on account of the cooling effect of this unnecessary air. Heat evolved from the combustion of gases must then go to heating up large quantities of nitrogen introduced with the excess air, causing a larger proportion to be lost in the stack gases.

The loss due to combustible falling through the grate is generally small with properly designed grate bars. In practice it amounts to about 0.5% to 1% of the total heat balance. When fires are cleaned, a larger amount may be lost, being hauled out with the clinkers.

Loss due to moisture in fuel and air depends upon the atmospheric conditions and the moisture in coal. This loss is due to heat required to convert water to steam and superheat this steam to the smoke-stack gas temperature. This loss rarely exceeds 4%.

As the rate of steaming increases (*i. e.*, more coal burned per square foot of grate surface per hour), the furnace efficiency decreases. This falling off of efficiency is due to the fact that at high steaming rates the combustion of the gases evolved from the fuel localizes further and further away from the fuel bed. As the gases are being evolved in larger quantities, more space and more time are required for the proper mixture of these gases with the necessary air for combustion. The gases are forced through the combustion space faster, and do not have time to mix properly with the air before striking the cooler heating surfaces and becoming chilled below their ignition temperatures. The result is a larger loss due to the incomplete combustion of carbon and hydrocarbons to CO.

Amount of Air Required Over the Grate.—When coal is first thrown on the fire, a large amount of volatile gases are distilled off, requiring a large amount of air for their complete combustion. The amount of volatiles and the duration of this process of distillation depend upon the coal and the furnace temperature, being greater for bituminous than for anthracite coals. The usual practice has been to admit air over the grate through holes in the furnace door for the combustion of these volatiles, resulting in large amounts of excess air being admitted after the larger part of the volatiles had been driven off. This practice is being discontinued for two reasons: (1) The excess air admitted through holes in the furnace door does not necessarily combine with the volatiles and effect complete combustion. Some of the air travels through the combustion space in streams without mixing with the volatiles. (2) After the first minute succeeding the firing of a fresh charge, the distillation of volatiles is considerably diminished, and all air admitted over the grate is in excess of the amount required for combustion. The result is the chilling of the heating surfaces, and the reduction of the boiler efficiency.

At the Engineering Experiment Station, at Annapolis, Md., it is now the practice to exclude all air over the grate, and to seal all openings in the furnace doors. When making tests, the furnace doors are closed as quickly as possible after a fresh charge is fired. It must be borne in mind, however, that the fires must be carried as *thin* as possible without allowing holes to form in the fuel bed.

The foregoing applies particularly to the semi-bituminous coals, such as Pocahontas coal, usually purchased for the U. S. Naval Service. When bituminous coals high in volatile matter are used,

a small amount of excess air admitted over the grate may be essential to combustion, particularly if the fuel bed forms a thick, pasty mass, preventing the flow of air through the fuel bed.

Leaks in the Boiler Casing.—Air leaks through the boiler casing are extremely detrimental to boiler efficiency, and are usually difficult to locate. Air entering the boiler in this manner *does not promote combustion* since the gases are chilled below their ignition temperature by contact with the relatively cooler heating surfaces. Such leakage represents, therefore, a direct loss, since it takes heat from the hot gases of combustion and increases the smoke-pipe loss. The amount of air which may leak through a small opening the size of a pin hole is not often appreciated.

Such leaks are best discovered by holding the flame of a lighted candle near the casing, when any leaks will be made apparent by the flickering of the flame towards the hole. These holes must be carefully stopped up by putty or some material which will effectively seal the opening.

CHAPTER VIII.

NOTES ON BOILER DESIGN.

Boiler Horse-power.—In engineering work, the term "horse-power" has two meanings: (1) An absolute unit or measure of the rate of doing work, equal to 33,000 foot-pounds per minute; and (2) an approximate measure of the size, capacity or rating of a source of energy.

In the case of a boiler, the true *boiler horse-power* refers to the capacity of a boiler to evaporate water into steam at a certain rate under given conditions.

The unit of boiler horse-power adopted by the A. S. M. E. is as follows: 30 pounds of water evaporated into dry steam per hour from feed water at 100° F., and under a pressure of 70 pounds per square inch above atmosphere. The unit of power is equivalent to the development of 33,479 heat units per hour. This is also equal to the equivalent evaporation of 34.5 pounds of dry steam from and at 212° F. The term "boiler horse-power" is, therefore, only a measure of *capacity*. It is largely used as a commercial designation of boiler capacity and is rather loosely applied.

Boiler Efficiency.—The *efficiency* of a boiler is the quotient of heat transmitted to the water per pound of fuel burned divided by the total heating value of a pound of fuel. In actual boiler tests the determination of boiler efficiency is based on the weight of dry coal free from ash, and the amount of fuel as fired is corrected for this factor. The boiler efficiency (E_B), therefore, is represented by the equation

$$E_B = \frac{\text{heat absorbed per lb. of combustible}}{\text{heating value of 1 lb. of combustible}}$$

The term "combustible," in boiler tests, means coal containing no moisture and entirely free from ash.

The efficiency of the boiler is the product of the heating surface efficiency and the furnace efficiency. The *heating surface efficiency* depends upon the shape and length of the gas passages around the heating surfaces and the amount of surface exposed to the action of radiant heat. Since, by experiment, it is known that the effect of

radiant heat is practically constant for all rates of steaming, the efficiency of the heating surface is very nearly constant for all rates of steaming, increasing slightly at lower rates.

It has been shown that the *furnace efficiency* falls off very quickly after a certain fixed rate of combustion has been reached, depending upon the size and shape of the combustion space.

Since the boiler efficiency is the product of the heating surface efficiency and the furnace efficiency, the boiler efficiency falls off rapidly after a certain steaming rate is reached, and any further forcing results in an increased loss of efficiency; this with the most expert firing and careful regulation of furnace conditions.

It is evident, therefore, that poor firing, improper thickness of fires, and inattention to proper air supply will result in a serious loss of boiler efficiency, and therefore of fuel economy. Poor firing may result in the overall boiler efficiency being reduced from 75% to 50%, or even lower.

Setting losses are losses caused by the leakage of cold air through small holes or cracks in the boiler casing. Such air entering the gas passages does not aid in the combustion of unburned gases, but causes a loss, due to the chilling of the heating surfaces and to the dilution and chilling of the hot gases. The loss of efficiency from this source may amount to as much as 10% if there is serious leakage. Such losses naturally increase with increased draft.

Setting losses can only be reduced by a careful examination of the boiler casing for pin-holes and cracks, by observing the action of the flame of a lighted candle. In the vicinity of a leak in the casing, the flame will be drawn toward the opening. All such holes and cracks should be carefully stopped with some material such as fire-clay or powdered asbestos mixed with water.

General Requirements for Naval Boilers.

Boilers for use in the naval service should be designed for **high capacity.** This means that the boiler should be capable of an equivalent evaporation of from 10 to 20 pounds of water per square foot of heating surface per hour. The greater the capacity, the greater will be the saving in weight and space.

High efficiency is the second requirement for naval boilers, and a type combining high capacity with high efficiency is desirable.

Accessibility for cleaning and ease of repairing are important requisites, since boilers require frequent cleaning, and should be capable of being repaired by the ship's force.

Simplicity of construction, together with a certain amount of flexibility, is an important feature in boiler design. The multiplicity of joints, nipples and parts liable to distortion and leakage under steam should be avoided. The design should permit the rapid and easy removal of defective or injured parts, such as generating tubes, nipples, cross-boxes, etc.

General Discussion.

Horse-power.—When a new ship is being designed, and after her general characteristics have been determined, a model of the bare hull is constructed to dimensions and pulled through the water at different speeds in the model basin in the Navy Yard. Washington. The power necessary to pull the model through the water at each speed is carefully ascertained, and from the data obtained an *effective horse-power curve* is constructed. From this curve the effective horse-power necessary to drive the bare hull of the vessel at any desired speed can be found. The effective horse-power curve for the bare hull is constructed under the care of the Bureau of Construction and Repair of the Navy.

The effective horse-power curve is then sent to the Bureau of Steam Engineering, where the designs for the propulsive machinery and boilers are made. In this Bureau there are records of all of the data obtainable from the trial trips of all vessels of the Navy, and from those of similar vessels of other countries where such data could be obtained.

The Bureau of Steam Engineering, having ascertained the maximum effective horse-power necessary to give the vessel her maximum designed speed, then decides upon the type of propelling machinery and type of propeller to be used.

Having decided on the type of propeller, they then look up the data of some vessel of similar hull and propellers and determine the efficiency of her propeller at the maximum speed of the vessel through the water; these efficiencies run from 50% to 60%. From the propeller efficiency and other data of the similar vessel a *propulsive coefficient* is obtained. The propulsive coefficient, at the maximum speed, is the ratio of the effective horse-power necessary to pull the bare hull through the water at maximum speed to the total horse-power necessary for the engines or turbine to drive the vessel through the water at the same speed under the same conditions.

Having the total effective horse-power and the propulsive coefficient, the *total horse-power* for the engines is obtained. The total horse-power (H. P.) equals effective horse-power (E. H. P.) divided by the propulsive coefficient.

From the data of many trial trips of naval vessels it has been ascertained that the horse-power for the auxiliary machinery of a vessel driven by steam varies between 5% and 6% of the total engine horse-power at full power.

The total horse-power, when at maximum speed, of a vessel having reciprocating engines consists of the indicated horse-power (I. H. P.) of the main engines plus the I. H. P. of all of the steam-driven auxiliaries; that of a vessel having turbines consists of the shaft horse-power (S. H. P.) of the turbine plus the I. H. P. of the steam-driven auxiliaries. The steam for operating the evaporating plant is not included in the above.

The B. H. P. of a reciprocating engine is generally from 90% to 92% of the I. H. P. of that engine.

Having obtained the total engine horse-power, it is necessary to design a boiler installation that will give that horse-power plus the horse-power for the auxiliary machinery, and still have some reserve power.

Water Rate.—From the records of trial trips of the latest vessels the water rate per horse-power of the main engines can be found. The *water rate* is the *pounds of steam per horse-power per hour.*

In the design of the boiler plant a water rate is assumed that is high enough, above the actual water rate of the main engines, to give the steam for all the auxiliaries and still have a reserve. As an example: In designing the boilers for one of the new battleships the water rate per hour was taken as 18 pounds for the main engines alone. On the trial trip the water rate was found to be 13.38 pounds for the engines alone and 14.32 for the turbines and all auxiliary machinery in use on the trial. This gives 25.7% excess of steam for power other than for the main engines and 20.5% excess above that required for all of the steam-driven machinery in use.

The water rate for boiler design for large boilers to be used with turbines or reciprocating engines is taken as 18, which gives an ample allowance for all machinery on the vessel, with approximately 20% excess of steam. In designing small boilers, in which liquid fuel is to be burned, to be used with steam turbines the water rate is taken as 15, which gives about 10% excess of steam.

The total engine horse-power multiplied by the assumed water rate gives the total number of pounds of steam required per hour.

Heating Surface.—From boiler trials it has been found that one square foot of heating surface evaporates about 9 pounds of feed water per hour at the temperatures corresponding to the boiler pressures required for modern engines, without forcing.

Grate Surface.—If the boilers are to be coal-burning, the grate surface is derived from the heating surface. The ratio of grate surface to heating surface equals 1 square foot to 44.5 square feet. If the boilers are to be liquid-fuel-burning, there must be some ratio between the furnace volume and the heating surface. Just what the best ratio is has not yet been definitely fixed. In the Yarrow boilers in the destroyers the ratio of furnace volume to heating surface is about 1 cubic foot to 8.6 square feet, and in the Normand boilers it is about 1 to 14.4.

Tentative Plans.—The drawings of the compartments in which the boilers are to be installed are now obtained from the Bureau of Construction and Repair, and tentative plans are made. The boilers are so arranged (1) that the grates of coal-burning boilers are not too long to be fired properly, generally not over 6½ feet to 7 feet; (2) that there is room between the boiler fronts and bulkheads for the boilers to be fired and worked properly; (3) and that no part of the boiler comes above the protective deck. The plans are then considered and a type of boiler is decided upon that will give the proper number of square feet of heating surface with proper furnaces, and the best arrangement in available boiler compartment space.

Strength Calculations.—The thickness of tubes, drums, headers and nipples for water-tube boilers are then calculated for the maximum test pressure by the rules for thin cylinders found in any textbook on machine design. If fire-tube boilers are decided upon, the thickness of shells, heads, combustion-chamber sheets, tubes, braces and stays are calculated from the general rules of machine design.

After the arrangement and numbers of the boilers have been decided upon, tentative plans of steam and feed piping are made and a plan is adopted.

Size of Piping.—The sizes of the main steam pipe and branches are then calculated, allowing a mean velocity of steam of from 6000 feet to 7000 feet per minute. Having the pressure of the steam in the pipes, the density of the steam at that pressure, from the steam tables, and the quantity that each branch is to deliver, the

area of the opening in a cross-section of the pipe and, therefore, the diameter of the pipe, are easily calculated.

The velocities in the different branches are so arranged that the boiler the most distant from the engines can supply its full quota of steam to the engine, *i. e.,* the branches to the boilers should be so arranged that each boiler will supply its full quota of steam to the main steam line at the same pressure as any other one.

Feed Piping.—The feed lines are calculated in the same manner, having the quantity of water to be delivered to each boiler, and its pressure; a velocity of water in the branches to the different boilers is assumed from 300 feet to 400 feet per minute, from which the diameter of the feed main and its branches to the boilers are calculated so that each boiler will get its proper quota of water.

The area of the openings through the valves in the main steam and feed lines is always slightly greater when the valves are wide open than the area of the opening through the pipes to which they are attached.

The thicknesses of all pipes are calculated from the following formulæ:

$$\text{For straight copper pipe, } T=\frac{P\times D}{8{,}000}+\tfrac{1}{16}''.$$

$$\text{For steel pipe, } T=\frac{P\times D}{10{,}000}+\tfrac{1}{16}''.$$

P = pressure above the atmosphere in pounds per square inch.
D = inside diameter of pipe in inches.
T = thickness of pipes in inches.

Air Supply.—The total area between the grate bars in the furnace of a coal-burning boiler must be sufficient to pass 250 cubic feet of air per hour at a velocity of 30 feet per second through the fire for each pound of coal burned. The openings through air cones of an oil-burning boiler must pass into the furnace 300 cubic feet of air for each pound of oil burned per hour, when the air is under the designed maximum draft pressure.

Gas Passages.—The area through the tubes of a fire-tube boiler or around the tubes of a water-tube boiler for the gases of combustion must equal .143 ($\frac{1}{7}$) times the grate area or .0032 times the heating surface.

The passage through the uptakes for the passage of these gases must equal .143 times the area of grate or .0032 times the heating surface of the boiler.

The passage through the smoke-pipe for the gases of combustion must equal .0032 times the heating surface of all of the boilers connected to that stack.

If there are battle bars fitted in the uptakes, the area through them must equal .167 times the area of the grate or .0037 times the heating surface of the boiler to which that uptake is connected.

Steam Spaces.—The volume of the steam space in the shell or steam drum must be sufficient to allow the boiler to furnish practically dry steam through the dry pipe to the steam drum.

Fire-room Space.—When boilers are placed in double fire-rooms, to allow for removal of tubes and handling of firing tools there must be at least 11′ 6″ clear space between the fronts of the boilers; in single fire-rooms there must be sufficient space between the boiler front and the bulkhead to permit of the withdrawal of a tube through the front headers or tube sheets.

Passages between boilers must be at least 3 feet wide.

Materials.—Materials of which boilers are constructed for vessels in the naval service:

Welded or flanged plates are of Class B open-hearth steel. Other plates are of Class A or Class B open-hearth steel.

All rivets are open-hearth steel, Class A, or Class B, in conformity with the class of the plates that are connected by them. All boiler-pressure parts are constructed entirely of open-hearth steel plate; the tubes and headers are of seamless steel.

No malleable or cast-iron parts are allowed in the parts under pressure.

No screw joints are allowed in contact with the fire except in steam-launch boilers.

Boiler tubes are made of cold-drawn seamless steel. The thicknesses of boiler tubes are generally given in British wire-gage units and are as follows, depending on the outside diameter:

4″ tubes are No. 6 B. W. G.=.203″ thick.
3″ tubes are No. 6 B. W. G.=.203″ thick.
2″ tubes are No. 8 B. W, G.=.165″ thick.

Hydraulic riveting is now required on all boiler seams, and all seams are caulked on both sides. Manhole and handhole plates and dogs are made of forged steel.

Grate bars are made of cast iron.

Grate-bar bearer bars are made of forged steel.

Dead plates, door liners, lintels and door jams are made of cast iron.

Furnace doors are made of wrought iron.

Ash pans, ash-pan doors and boiler casings are made of galvanized Class C boiler-plate steel.

All internal pipes in boilers are now made of steel.

The uptake, breeching and smoke-pipes are constructed of materials as follows:

Rivets, Class C steel-rivet rods.

Forgings, Class C steel.

Shapes, Class C steel.

Hinges and latches, Class C steel, cast or forged.

Plates, Class C boiler-plate steel.

Lagging material used is magnesia. It is covered with Russian iron, galvanized iron or heavy canvas.

The materials of which the fittings and piping are made are as follows:

Feed check and feed stop valves, composition.

Valve springs, composition.

Bottom blow-valves, composition.

Surface blow-valves, composition.

Boiler drain cocks, composition.

Boiler air cocks, composition.

Boiler gage cocks, composition.

Boiler water gages, composition.

Frames and fittings, composition.

Glasses, best annealed glass with fused ends.

Grommets, vulcanized rubber.

Pipes less than 2″ in diameter, seamless-drawn copper.

All steam pipes 2″ and over in diameter, seamless-drawn steel.

Oil-fuel pipes, suction and service, seamless-drawn steel.

Flanges for steel pipes, Class B forged steel.

Flanges for copper pipes, composition.

Fittings for steel steam pipes, Class B cast steel or composition.

Fittings for copper pipes, composition.

All external fittings on boilers, cast steel or composition.

CHAPTER IX.

COAL.

Formation of Coal.—Many centuries ago, according to geologists, the coal we now use was a mass of damp decaying vegetable matter. The mass, had it been analyzed, would have shown, roughly—water 50%, carbon 25%, hydrogen 3%, oxygen 20%, nitrogen .5% and ash 1%. The decaying vegetable matter was gradually covered with mud, which eventually hardened into slate. From various causes, such as glacial movements, volcanic upheavals, contraction of the earth's crust, etc., this vegetable matter was subjected to high pressures and temperatures, and a distillation under pressure took place. During the distillation most of the water and volatile matter was driven off, and the coals now mined are the result.

The conditions under which this distillation took place in various parts of the world were not the same, resulting in different kinds of coal in different localities.

The products of the distillation vary, in different localities, all the way from the original peat, through the lignites, and the bituminous and semi-bituminous, semi-anthracite and anthracite coals, to the graphitic coals.

There are, then, different varieties of coal due to the extent to which the volatile gases have been driven off from the original peat or other woody coal-forming substances. There are also different qualities in each variety of coal, due to varying percentages of ash and water. The ash varies from 2% to 30%, and the water from 1%, in the anthracites, to 14% in some bituminous coals, and to 25% or more in the lignites. The water is held in coals by capillary attraction or some similar force, and the coals have to be heated to about 250° F. to drive off.

Peat, the first product resulting from the decay of vegetable matter, is the partly carbonized organic matter of bogs, swamps, etc. It is principally composed of moss, reeds, ferns and similar plants, and is found in low marshy areas. Near the surface, peat is brown in color and spongy; deeper down, where more decomposed, it is darker in color and more dense. Peat contains a large amount of moisture unless specially prepared. Good air-dried peat contains about 25% of moisture. The heating value of peat is so low that it cannot be used as a fuel in marine boilers.

Lignite, or brown coal, is only slightly removed in character from the original vegetable matter. It retains about one-third of its original water and a large percentage of hydrocarbon gases and oxygen. Lignites include all the varieties of coal between peat and the bituminous formations. They are usually brownish in color, and are high in percentage of ash. They contain a large percentage of water, and their heating values are much lower than those of the other kinds of coal. In some parts of the world lignites, compressed into briquettes, are used as fuel for boilers.

Cannel coal differs from the lignites in that it contains a relatively high percentage of hydrogen. It lights readily and burns with a bright, steady flame. It is very compact, is dull in appearance, and does not soil the hands when handled. It differs from the ordinary bituminous coal in its texture. It is rich in volatile matter, and is used extensively in gas manufacture.

Bituminous coal is a soft, black coal, greasy in appearance, and is found practically all over the world. It contains more carbon and disposable hydrogen, but less oxygen, than the lignites. It is hygroscopic in character, the amount of contained water depending on the relative humidity of the air and on the size of the lumps. Small-lump coal, having a relatively greater surface exposed to the air, will hold more moisture than coal of larger lumps.

According to their behavior when being burned, bituminous coals are sometimes classified as *coking* or *non-coking* coals. The former undergo an incipient fusion, or softening, when heated, so that fragments coalesce and yield a compact coke. The latter preserve their form, producing a coke which is serviceable only when made from large pieces of coal. They are also sometimes classified as *long-flaming* and *short-flaming* coals. A long-flaming coal contains a high percentage of volatile matter, and burns in the ordinary furnace with a long flame, due to the difficulty of supplying the volatile matter with a sufficient quantity of hot air to cause its complete combustion.

Semi-bituminous coal is black in color, is harder than the varieties already mentioned, and is remarkably uniform in composition. It contains very little oxygen, and is low in moisture, ash, and sulphur. The amount of volatiles usually varies from 17% to 22% of the combustible matter. It is found in England, Wales and the eastern part of the United States. This coal ranks as the best steaming coal in the world.

Anthracite coal is dense black in color, and is compact, hard and lustrous. Its structure is homogeneous. It does not ignite easily, and it burns with a feeble, smokeless flame, giving off intense heat. It is non-coking. The powdery coke made from it has no commercial value. Anthracite coal is found in England, the eastern part of the United States, and Colorado.

Semi-anthracite coal has characteristics intermediate between those of semi-bituminous and anthracite.

Patent Fuel.—In order to utilize the small coal or slack at the mines, various plans have been tried, of which the *patent fuel,* or *briquette,* is the only one useful for marine use. The briquette generally consists of fine coal with some form of binding material. Tar and pitch are the best binders; lime, clay or cement give too much ash. The fine coal and binder are mixed, baked until the volatiles are driven off, and then pressed into bricks. These stow well and have a heating value depending on the heating values of the coal and the binder.

Graphitic coal, found in Rhode Island, has been deprived by distillation of practically all of its hydrocarbon gases and oxygen; it consists of fixed carbon and ash.

Powdered Coal.—*Powdered coal* is coal which has been finely pulverized by machinery. It is forced into the furnaces through pipes, and is completely burned without smoke, yielding high furnace efficiency, particularly on account of the possibility of obtaining complete combustion without excess air. The use of powdered coal permits the use of inferior grades of coal, since the percentage of ash and moisture has very little effect on the combustion. Furnaces may be forced to a higher rate when powdered fuel is used.

The disadvantages are: The necessity for high-grade fire brick to withstand the high furnace temperature, and the danger of explosions due to the mixture of coal dust and air. For naval purposes, the weight and space for necessary additional machinery are also disadvantageous.

Powdered coal as a fuel has not been adopted in the U. S. naval service.

Classification of Coals.—Coals are classified according to the relative percentages of carbon and volatile matter contained in the combustible portion. The following table gives the characteristics of the combustible portion in the different classifications, as determined by what is known as the *proximate analysis.*

Classification.	Per cent fixed carbon.	Per cent volatile matter.	Heating value per lb. of combustible in B. T. U.	Relative value of combustible. That of semi-bituminous=100.
Anthracite	97.0–92.5	3.0– 7.5	14,600–14,800	98
Semi-anthracite	92.5–87.5	7.5–12.5	14,700–15,500	96
Semi-bituminous	87.5–75	12.5–25	15,500–16,000	100
Bituminous—Eastern	75.0–60	25.0–40	14,800–15,500	96
Bituminous—Western	65.0–50	35.0–50	13,500–14,800	90
Lignites	Under 50	Over 50	11,000–13,500	77

Proximate Analysis.—There are four different factors in the quality of a coal that can be determined by a proximate analysis: (1) Moisture; (2) volatile matter; (3) carbon; (4) ash. A proximate analysis of coal is made as follows:

1. From a weighed sample, say a gram, of coal, the moisture is first driven off by heating it to a temperature of from 250° to 300° F. for a given time. The sample is then reweighed, and the per cent of loss of weight is the percentage of moisture.

2. The volatile matter is then driven off by heating the sample in a closed crucible to a red heat for a short time. It is then reweighed and the loss is the volatile matter that has been distilled off.

3. The carbon is burned out of the remaining coke by keeping it at a white heat with a plentiful supply of air until nothing is left but ash. The ash is then weighed and the difference between its weight and that of the coke burned is the fixed carbon.

The **heating value** of a coal depends upon its percentage of total combustible matter and upon the heating value per pound of that combustible. The latter differs in different districts; it is highest in the semi-bituminous coals, having nearly a constant value of 15,750 B. T. U. per pound of combustible. When the percentage of moisture and ash in any coal is known, the heating value per pound may be found approximately as follows: Obtain from a table (see following table) of data the average heating value per pound of combustible for the district from which the coal comes. Multiply this by the difference between 100% and the sum of the percentages of moisture and ash.

In selecting coal for a given type of boiler, consideration of its theoretical heating value alone might lead to false conclusions as to its suitability. The ratio of carbon to volatiles and the combustion chamber space must be taken into account, as high volatile coal will not be efficient in a boiler with restricted combustion space, while it would be in one with ample space.

The following table gives the heating values of various coals, and of various patent and liquid fuels. It also gives the ultimate analysis, which is a quantitative chemical analysis; such analyses should be performed only by competent chemists.

CHEMICAL COMPOSITION OF VARIOUS STEAMING COALS AND LIQUID FUELS, THEIR HEATING VALUES AND THE VOLUME OCCUPIED BY ONE TON.

Name of fuel and country from which obtained.	Ultimate analysis.						Proximate analysis.				Heating value of one pound of dry fuel in B. T. U.	Number of cubic feet occupied by one ton of 2240 pounds of fuel.
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Fixed carbon.	Volatile matter.	Ash.	Moisture.		
Anthr. and Semi-Anthr.												
Pennsylvania, av..........Am.	....	....	....	....	....	......	85.6	4.0	6.3	1.2	13,100	42.4
Lehigh, Pa................ "	85.7	2.8	2.9	.8	.5	7.3	86.5	4.3	7.2	2.0	......	....
Drifton, Pa............... "	87.7	2.6	2.3	1.0	.4	8.0	89.1	3.6	5.9	1.4	13,722	....
Nixon's Navigation.... Wales	87.7	4.0	2.5		5.8		....	....	....	....	15,010	....
Powell's Duffryn....... "	88.3	4.6	.6	1.4	1.8	3.3	....	....	....	....	16,108	....
Isère.................... France	90.0	1.5	1.5		7.0		....	....	....	....	13,782	40.0
Semi-Bituminous.												
Pocahontas, W. Va........Am.	83.5	4.8	4.2	1.3	.7	5.5	77.3	17.1	5.1	.5	14,578	44.1 av. Am.
New River, W. Va........ "	83.6	4.7	4.5	1.6	.7	4.9	72.7	21.7	4.8	.8	14,488	
George's Creek, Md....... "	81.0	4.9	4.6	2.2	.7	6.6	74.3	18.5	6.6	.1	13,987	
Clearfield, Pa............ "	80.2	5.1	4.7	1.4	.9	7.7	73.2	18.8	7.6	.4	......	
Cardiff, av.............. Wales	83.8	4.8	4.1	1.0	1.4	4.9	80.	17.	3.	....	......	42.7?
Newcastle................Engl.	82.4	5.5	6.3	1.6	1.3	2.9	....	....	....	....	14,820	....
Bituminous.												
Pittsburgh, steaming..... Am.	76.5	5.2	8.1	1.4	1.2	7.6	59.1	32.0	7.5	1.4	13,280	....
Pratt seam, Ala.......... "	....	....	....	....	....	......	63.8	31.5	3.5	1.2	14,580	....
Washington State, av..... "	....	....	....	....	....	......	57.7	32.3	8.3	1.2	......	45.5
Br. Columbia, av............	....	....	....	....	....	......	56.5	33.7	8.1	1.3	......	
Scotch, av.....................	78.5	5.6	9.7	1.0	1.1	4.1	.. .	....	....	....	12,870	45.0
Miike................... Japan	75.0	5.8	?	1.1	3.2	12.0?	....	....	....	....	......	45.6
Chilean, av....................	63.6	5.4	14.8	.8	2.5	12.9	....	....	....	....	11,030	46.5?
Batan Island.............P. I.	....	....	....	....	.5	......	45.	40.	5.5	9.	......	....
Patent Fuel												
British, av.....................	83.4	5.0	2.8	1.1	1.3	6.4	....	....	....	....	15,000	34.4
Warlich's................Engl.	90.0	5.6	....	....	1.6	2.8?	....	....	....	....	16,495	....
French, av.....................	....	....	....	....	....	3.3	....	....	....	....	15,000	34.5
Liquid Fuel.							Sp. Gr.	Flash.	Fire.			
Pennsylvania, kerosene........	85.0	13.5	1.5	....	....	......	.784	120°	150°	....	20,156	
Pratt's fuel oil, Pa...........	....	....	....	....	....	......	.852	200	268	....	19,980	34-36 35.0 av.
Eagle fuel oil, Pa............	....	....	....	....	....	......	.849	249	296	....	19,742	
Beaumont, Tex., distilled.....	83.3	12.9	3.8	....	.5	......	.926	216	240	....	19,480	
Kern River, Cal., distilled....	84.4	11.0	3.4	.6	.6	......	.962	228	258	....	18,806	
Astatki, Baku,* Russ..........	85.0	13.7	1.3	....	....	......	.940	....	....	2.0	18,560	
Borneo, crude..................	83.4	10.3	6.3	(incl. impurities)			.960	....	....	12.0	18,000	
Burma, refuse*.................	86.0	12.4	1.6	....	....	......	....	....	.. .	....	18,860	

* After sulphur and other impurities have been removed.

Quality of a Coal.—The actual evaporating capacity of a boiler, containing a given amount of heating surface and a given grate area, depends primarily upon the quantity of heat which may be generated in the furnace. This depends upon the quantity of coal that may be burned and upon its quality. The better the quality, the greater the number of heat units generated by the combustion of each pound. If the coal is high in moisture or in oxygen, not only will the heat units derived from the combustion of it be low, but the attainable temperature will be lower than that from a better coal. If the coal is high in ash, not only is the value per ton diminished, but the quantity of ash formed on the grate tends to check the air supply, to diminish the rate of combustion, and consequently the quantity of steam generated. If the coal is high in sulphur in the form of pyrites, the ash will fuse into clinker and this may choke the grate completely, necessitating frequent cleaning of the fires.

The quality of the coal is, therefore, a most important factor of both capacity and economy of a boiler. It is possible to obtain from the same boiler, with the same fireman and the same draft, twice as much steam when using a good free-burning coal as can be obtained when using poor coal.

Ash and Clinker.—The presence of ash in coal is objectionable in many ways. It not only represents so much waste material, but also carries away a considerable quantity of unconsumed carbon when the fires are cleaned. This indirect waste is frequently as much as 50% of the theoretical ash constituent, so that 5% of ash by chemical analysis becomes 7½% in practice. Ash clogs the fire and necessitates more frequent cleaning. This tends to depreciate furnace efficiency, and requires extra labor from the fireman.

Ash not only acts as a diluent in the coal, but also retards combustion to such an extent that the boiler efficiency becomes rapidly impaired. It has been shown that, with a Babcock and Wilcox boiler, when the percentage of ash on the grate reached 40% of the coal, the useful effect of the fire fell to zero. In other words, such a fire as could be maintained only sufficed to make good radiation losses.

The composition of ash varies. Roughly, it consists of about 50% silica, 30% to 35% alumina and oxide of iron, about 4% to 8% of lime, and a small per cent of sulphuric acid. The sulphuric acid and the iron oxide are derived from the iron pyrites (FeS_2, sulphide of iron), which is often found in many coals, and is mainly respon-

sible for the formation of clinker, as the iron oxide forms a flux for the silica, the fusibility of which is increased by the presence of lime. The most refractory ash is that containing the smallest percentage of lime and iron oxide. When the percentage of lime is about half that of the silica, a very fusible slag is produced. Although its heating value is not impaired by contact with sea water, salt is a bad ingredient in coal, as it increases the fusibility of the clinker, and the hydrochloric acid liberated in its decomposition is very corrosive. The mixing of coals will sometimes cause them to produce slag and clinker, although each separately will give a fairly refractory ash. This is due to ash of one coal possessing an excess of ingredients which provide a flux for the ash of the other. The incombustible elements in coal are not evenly diffused, and consequently the resulting ash or slag is unevenly distributed over the grate, and after a time it accumulates in places to such an extent as to choke the air spaces and necessitate cleaning the fires. Some slags cause deterioration of the grate bars by fluxing with the oxide of iron on their surfaces and eating them away.

Coals high in sulphur generally give a very fusible ash, on account of the iron with which the sulphur is combined. The amount of ash varies greatly, ranging from 2% to 30%, or more. It varies with the district in which the coal is mined, with individual mines in that district, with parts of the same mine, and with the care taken in mining it. With anthracite coals it varies with the size of the lumps, the larger sizes giving the least ash.

Specification for Coal.—Semi-bituminous and bituminous coals are the only ones in general use in the United States Navy.

Coal is bought for use under various specifications, generally written to suit the conditions under which the coal is to be used. Barring place of delivery and price, the most important clause under the latest navy specification for coal for naval vessels reads as follows: "The coal delivered under contract must be of the best quality—New River Admiralty Smokeless run of mine coal with a fair proportion of lump—must be dry and practically free from slate, dirt, sulphur and other impurities and subject to the usual inspection and test. Coal to be inspected for quality and quantity at point of shipment."

Kent's "Steam Boiler Economy" gives a definition of the standard coal as follows:

"The standard coal is a semi-bituminous coal containing not over

20% of volatile matter, 2% of moisture and 6% of ash, the remainder being fixed carbon, the determinations being made by proximate analysis."

A very good specification for buying coal would be as follows: Coal to have not over .8% of sulphur. A reduction of 1% in the price to be made for each 1% of volatile matter in excess of 25%; also a reduction of 2% for each 1% of ash, and 2% for each 1% of moisture in excess of the standard.

Effect of Moisture in Coal.—The presence of moisture in coal is objectionable because it has to be converted into steam and rejected at the temperature of the smoke-pipe gases, and the heat required to do this is lost. Under the ordinary conditions the moisture varies from 1% to 5%, though small coals will sometimes hold much more. The approximate heat loss will vary from 12 to 144 B. T. U. per pound of coal, according to its condition.

Effect of Weathering on Coals.—On being exposed to the weather the quantity of oxygen and indisposable hydrogen in coal, and the weight of the coal, will increase. The quantity of carbon and disposable hydrogen will diminish. There will be a reduction in the calorific value of the coal.

On an actual test three coals held at a temperature of 158° to 180° F. for 14 days lost on an average of 3.6% of their calorific value. If coal be piled in the open, and there is no rise in its temperature, it will not suffer any sensible change in calorific value. If there be a rise of the temperature, it loses carbon and disposable hydrogen by oxidation; it increases in absolute weight, on account of the increase in oxygen and indisposable hydrogen; there is no change in the amount of sulphur; and there is a loss in the total calorific value of the coal.

An excess of pyrites in coal tends to produce rapid oxidation and mechanical disintegration of the mass, with the development of heat, loss of coking power and spontaneous ignition. In coking coals, weathering reduces and finally destroys the coking power, while the pyrites are converted from the state of the bisulphide into the comparatively innocuous sulphates.

Storage of Coal Under Water.—Experiments have been conducted in the last few years with a view to determining the effect on coal of storage under salt water. These experiments lead to the conclusion that underwater storage prevents the reduction of calorific value occurring with weathered coals and prevents spontaneous combustion.

Stowage* on Board Men-of-War.—Coal is stowed in bunkers. There are generally two tiers of them. The lower tier extends vertically from the inner skin of the ship to the protective deck, and is ranged alongside of the fire-rooms and engine-rooms, and sometimes athwartship between the after fire-rooms and forward engine-rooms and between the forward fire-room and forward part of the ship. Those forward and abaft the fire-rooms communicate with those abreast the fire-rooms, and those abreast of the fire-rooms communicate with the fire-rooms by means of water-tight doors. Those in the upper tier are between the protective deck and the second deck, and extend from the ammunition passages to the side of the ship. They communicate with the bunkers of the lower tier by water-tight doors leading into the lower bunker-filling chutes, and in the latest ships they have chutes leading directly to the fire-rooms; they generally communicate with other upper bunkers through water-tight doors.

All bunkers are filled through filling chutes leading from the upper, main or second decks. They have ventilating pipes leading from the highest point in them to the atmosphere. This is for ventilating the bunkers and for carrying away any gases that may be given off by the coal.

Chutes for filling the lower bunkers are placed as nearly as possible directly over the doors leading into the fire-rooms. The upper bunkers have doors opening into these chutes for trimming the coal from them into the lower bunkers.

All bunkers have escape plates, which can be opened from the bunker, for the exit of any one caught in the bunker. They should be located as near as possible to the entrance of the filling chute, in order that, when the bunker is nearly full, the last man to leave the bunker may remain as long as there is room for him to work, and then enter the escape and work the coal down as it runs from the chute until the bunker is entirely full. If the escape is not located near the filling chute, space is always left in the bunker from the chute to the escape.

For the same reason, large bunkers have more than one filling chute. This prevents extra handling of the coal in stowing the bunkers. They also have trolley rails and trolleys for carrying the coal buckets to the fire-room doors.

* "Stowage" is the term for arrangements for placing and keeping coal on board.

"Storage" is the term for accumulating for use.

All swinging doors to bunkers open away from the bunker, except those doors to bunkers distant from the fire-rooms; they open into the bunkers nearer the fire-rooms. All bunker doors opening into the fire-room are vertical sliding doors.

All bunkers have automatic fire alarms that ring a bell when the temperature is above that for which they are set—usually 212° F. The bells indicate on an indicator suitably located.

Some bunkers have means for blowing steam into them for extinguishing any fire that may start in their coal.

Coal must not be taken on board wet if it can be avoided, and care must be taken to keep it dry in the bunkers, as moisture sometimes causes a rapid and dangerous generation of heat and gas, resulting in spontaneous combustion. Before the decks are washed down after coaling, the solid bunker plates must be replaced and made tight to prevent water from getting into the bunkers. Should there be any indication of spontaneous combustion, it must at once be reported to the officer of the deck and to the executive and commanding officers.

The ventilation pipes fitted to the bunkers must be kept clear, and they must always be kept open for ventilation, except when running the blowers and when a loss of air pressure in the fire-rooms through open bunkers would be caused thereby. The plates of all fixed coaling trunks and coal bunkers not provided with permanent ventilation fittings must be taken off periodically to ventilate these spaces. This must be done at frequent intervals after coaling, as the evolution of gas owing to the breaking up of the coal is very rapid during, and for some days after, the operation of coaling ship. It must be borne in mind that to secure efficient ventilation there must be at least two openings, one for the admission of pure air and another for the escape of foul air; and, where permanent ventilation fittings do not include both, the bunker plates must be taken off periodically as required above. Care must be taken to ventilate such bunkers thoroughly before any men are sent to work in them.

No open light must be permitted in a coal bunker, or within 20 feet of an opening into a coal bunker, until the bunker has been thoroughly ventilated and it has been ascertained, by a safety-lamp or other suitable means, that it does not contain explosive gas. Special precautions in this respect must be taken for a few days after coaling. In any case in which the distance of 20 feet is impracticable, the distance kept must be as great as possible.

During the intervals between steaming periods, and at other times when it may be done to advantage, the coal must be trimmed from the upper and more remote bunkers into close proximity to the bunker doors of the fire-rooms where it will eventually be required for use. This is specially important as preparatory to steaming at a high rate of speed, when a considerable supply of coal will be needed. The engineer officer must keep himself informed of the general distribution of coal in the bunkers.

Coal must not be stowed in the fire-rooms in such quantities as to interfere with working the boilers, or to cover up the handles or wheels of valves, or to get into the bilges, thereby possibly choking the pump suctions and strainers and endangering the safety of the ship.

Precautions Taken in Determination of Amount of Coal Received. —*Inspection of Cargo.*—The commanding officer of the first ship to coal from any chartered collier will cause inspection to be made of hatches to cargo holds, with the view of ascertaining if the cargo of coal is intact and has not been broached by the collier herself.

Inspection of Winches and Gear.—Commanding officers will have, in company with the master of the collier or officer detailed by him, an inspection made of deck winches and other appliances belonging to the collier, both before and after coaling, in order to avoid any dispute as to claims for damages of the collier's gear. Ordinary wear and tear not included.

The draft of the collier and of the ship coaling, forward, amidships, and aft, will be accurately taken before and after coaling.

Loss Overboard.—Sufficient screens will be spread between the ship and the collier to avoid loss of coal overboard by drag of bags along the collier's decks and rails. Screens will also be provided to prevent the loss of empty bags while being returned from ship to collier. Not over 1% loss is allowed for coal in handling from collier to ship.

A *sufficient number of tallymen* will be furnished each collier, by the ship coaling, to assist the master of the collier to tally bags as they come out of the holds. The ship coaling will have sufficient men stationed to tally accurately the number of bags hoisted on board. To determine the weight of a bag there will be detailed a weighing party under the charge of an officer. This party will be provided with accurate scales, and bags will be weighed continually during the coaling. The scales will be moved from time to time,

so that coal coming from all the hatches of the collier may be weighed. The average net weight of all the bags weighed will be the established weight of a bag of coal for that coaling. The average weight of empty bags will be accurately determined during every coaling.

In calculating bunker capacities, the former practice was to assume the density of the coal to be 43 cubic feet to the ton, and to assume bunkers stowable only to within 6 inches of the lower edge of the deck beams. In some cases the capacities of the permanent chutes were included; in other cases they were not.

The present standard practice is to assume the bunkers stowable to the lower edge of the deck beams, and on this assumption the capacity of the bunker is calculated for several different densities of coal, ranging usually from 41 to 44 cubic feet to the ton. Permanent chutes are now included in all calculations.

Tables of bunker capacities, calculated as described above, are furnished each new ship. Since the advent of the engineering competition, the bunkers of most of the principal ships, which were originally calculated at 43 cubic feet and to within 6 inches of the deck beams, have been recalculated in accordance with present standard practice, and tabular statements of results have been furnished the ships.

In vessels in which bunkers were measured according to the original practice and have not been recalculated in accordance with the prevailing practice, the bunkers should be recalculated by the engineer officer. As it is found practicable to stow most bunkers to the lower edge of the beams; and as the actual weight of coal in a bunker will vary considerably with varying densities of coal, bunker estimates will be unreliable unless this recalculation is effected and a table is prepared, showing the capacity of each bunker for each different density, and the density of the coal is accurately determined while coaling is going on.

During the coaling, *the density of the coal* will be determined by the officer in charge of weights, weighing at least once each hour a known number of cubic feet of coal. The receptacle used for this purpose shall contain not less than 16 cubic feet, and its capacity will be ascertained with the utmost accuracy. The density ascertained by the average of these hourly weighings will be the argument used in entering the aforementioned table, and the bunkers will be estimated in accordance with the stowage of bunkers and trunks,

which latter shall be ascertained by the senior engineer officer in person.

At the inspection before coaling begins, great care must be exercised in estimating the coal remaining in partially filled bunkers that are to receive more coal, and in converting the estimate into terms of cubic feet to be used in connection with the estimate of coal received in such bunkers during coaling. Coal used between the times of the first and second estimate must also be taken into consideration.

When coal is received from a source other than a chartered collier, the above regulations will be observed as far as they are applicable.

While a vessel is coaling, an hourly report of the amount of coal taken on board during the past hour will be made by signal to the division commander or senior officer present. If a ship has not been coaling during the entire hour, a time signal will be made with the amount taken on board. All such signals will be recorded by the ship sending them and by the ship receiving them. When the coaling is completed, signals will be made reporting that fact, together with the total taken on board during that coaling.

When a hold has been emptied, it will be swept clean of coal and the collier's deck also will be swept.

Receipt for Coal Received.—Immediately upon the completion of coaling from any collier, the commanding officer will give a written receipt to the master of the collier for the tons of coal received, and will send direct to the fleet flagship a duplicate of the written receipt.

When a collier is completely discharged by a vessel of the fleet, the commanding officer will report immediately the date, hour and minute of such completion of discharge, not only by written report but also by signal.

Coaling Ship.—Coal is purchased from the coal dealers on yearly contracts under the Navy Department Specifications. It is analyzed and tested at the Navy Yard, Washington, D. C. It is delivered to colliers or coal barges from cars. The amount of coal delivered to the collier or barge is determined by weighing the car in the presence of a government inspector before and after the coal is dumped.

The collier or barge is brought alongside of the ship to be coaled, and the coal is whipped up to the deck of the ship in coal bags of about 600 pounds capacity. This is done by means of the coaling machinery of the ship and collier, or, in case of a barge, by that of

the ship. Each bag is tallied as it comes on board by men of the ship's force stationed for that purpose, and about one bag in every ten is weighed, the average weight of coal per bag being calculated from the average of the total number weighed.

When brought alongside in a collier, the draft of the collier forward and aft is taken before and after coaling.

From the tons-per-inch curve of the collier a check may be made on the amount of coal received. Allowance must be made for any other weights received upon or discharged from the collier during the coaling.

The same measurements should be made on the coaling vessel, both before and after coaling; the amount, corrected as for the collier from the tons-per-inch curve of the coaling vessel, should agree with that from the collier.

Coal is whipped out of the hold of the collier by her own winches and booms and landed on the deck of the coaling vessel, tallied and weighed in the same manner as described above.

The bags are then taken to the bunker-filling chutes on trucks, and the coal is dumped down them. The details for filling the bags on the collier or barge, for running winches, for tending all gear on deck, and for weighing and trucking the coal to the bunkers and dumping it into the filling chutes, are from the gun divisions of the ship and the marines. After the coal is placed in the filling chutes, it is handled by men from the engineer's force. When the ship is built, the bunkers are carefully measured up to within 6″ of the lower edges of the overhead beams, and the capacity of the bunkers is calculated at the rate of 43 cubic feet of space per ton of coal.

Plans of the bunkers with these capacities are furnished the vessel with her outfit of plans, when she is first commissioned.

When the coal is poured into the bunkers, the engineer's force trim it away from the chute, filling the bunker to its utmost capacity. They keep the chute clear while the bunker is filled around them, until they cannot work longer to any advantage. After the bunker is filled so much that the last man can stow no more coal, he leaves the bunker either through the escape plate or the filling chute.

After the coal trimmer is out of the bunker, coal is dumped into the chute as long as it will run from the chute into the bunker. If the chute is a permanent fixture, it is also filled. The bunker is now considered to be full and is closed up. It is then assumed that

the bunker contains the amount of coal called for by the original bunker measurements. When each bunker is reported full, it is inspected; if it is not filled, the coal is worked back from the escape and more coal is added until it is full.

Before coaling is begun, the coal in all unfilled bunkers must be estimated carefully and the total amount on hand be ascertained. After coaling is finished, the estimate should be made again and the total amount taken on board be ascertained. If the estimates are carefully made, the amount found should agree, within 20 tons, with the corrected amount taken from the tons-per-inch curves of the ship and collier.

It is well to have a standard box on board ship, the cubic capacity of which, level with the top, is known accurately. While coaling is progressing, weigh this box, level full, get an average of ten weights, and calculate the number of cubic feet of space required per ton of the coal.

Records of Coal Consumption.—After coaling, the average net weight of ten buckets of coal taken from the bunkers is obtained and recorded.

As the coal is removed from the bunkers for use, each bucket is tallied, and at the end of each hour the water tender on watch gives to the machinist in charge of the steam log the number of buckets of coal used for each purpose. This machinist enters in the log, in the proper column, the number of buckets used. The log writer takes the record of the number of buckets per hour and, using the average weight, calculates the number of tons of coal used per day for each purpose and the total amount used for all purposes. He enters the amounts in tons and decimals (one place) in the proper columns for these entries on the smooth log sheets. This record is kept from midnight to midnight.

A second record is kept, similar to the above, for total expenditures of coal from noon to noon. The amount on hand at noon and the amount expended are signalled to the commander-in-chief or the senior officer present at noon of each day.

This record is checked by frequent inspections of all bunkers from which coal has been taken, and estimates are made of the coal in all such bunkers. The total amount on hand is determined in this way, and if the record has been kept correctly, the amount on hand by coal account and by estimate should agree. If it is found that they differ by 20 tons or more, the coal account should be

brought to show the amount on hand by an "expenditure or receipt by inspection" of the difference.

Coaling at Sea.—A method of coaling ship at sea has just been successfully tried out with the collier towing a battleship. The method consists of a trolley wire extending from a coaling boom on board of the collier to a boom or mast on the forecastle of the ship. This wire is kept properly taut by appropriate towing engines or winches. The coal in bags is whipped up to the trolley and sent over it to the ship, where it is lowered to the main deck and stowed in bunkers in the usual way. This method, devised by Ligerwood and Miller, has conformed to the contract requirements of delivering to a battleship coal at the rate of 60 tons per hour for six hours.

Storage of Coal and Spontaneous Combustion.—It has been found by experiment that all coals, except anthracite, when stored in the same way eventually ignite from spontaneous combustion, if the pile is over a certain definite number of feet (20) in height.

The length of time elapsing between that of the storage and that of the spontaneous ignition varies with the qualities of the coals. Those high in moisture and iron pyrites ignite first, and those of high volatile composition, containing much oxygen and moisture, come next. Coals of the above compositions heat in or near the center of the pile and give off gases. The rise in temperature and the smell of gas are the early indications of spontaneous combustion.

The most usual causes of local external heating are those due to heat from a boiler or steam pipe communicated to a coal bunker. If the bulkhead of a bunker containing coal with a tendency to absorb oxygen is kept at 120° F., there is a great chance of spontaneous ignition in a few days. Ignition may take place near the center of the bunker and with sufficient radiation would result in simply charring the coal. Waste, oily with fatty oils easily oxidized, may start a fire spontaneously, but mineral oil is said to retard heating.

Defective ventilation is that which renews air sufficiently to support combustion faster than it removes the heat to reduce the temperature below the point of ignition.

Coal should contain as large a percentage of lump and as little slack as possible, as in the latter resides the primary causes of spontaneous ignition. It should not have a high percentage of combustible volatile matter.

Coal should be at least a month from the mines, because it evolves marsh gas and absorbs oxygen more readily when it is newly mined.

It should not be loaded or stored in a wet or damp condition. The maximum percentage of moisture should be 3%, and that only when the coal is to be unloaded and used in the near future.

Ventilation is ordinarily effective on naval vessels, on account of the comparatively small amount of coal in the bunkers and the access at top and bottom. In colliers, however, perfect ventilation is impossible, on account of the amount of coal in the cargo spaces; and the cargo hatches should be battened down to exclude the fresh supply of air. Hatch covers, however, should be removed at times when the external air is cooler than the surface of the coal which shows signs of heating.

Thermostats are installed on naval vessels, to give warning of increase of temperature in bunkers; and in colliers, pipes plugged at the lower end should be driven into the hold for the purpose of dropping thermometers therein to get the temperature of the interior of the pipe.

When coal is heating, it gives out a characteristic and penetrating odor. The gases evolved consist of nitrogen, water vapor, carbon dioxide, carbon monoxide, hydrocarbons of a paraffin series, and sulphuretted hydrogen.

In a poorly ventilated bunker, in which spontaneous combustion is started, the gases, carbon monoxide and marsh gas, rise to the top of the bunker. By the time they reach the top of the coal they are cooled off and remain in the space above the coal. When mixed with the proper proportion of air, the result is a highly explosive mixture which a flame will set off.

Neither of these gases supports life, and carbon monoxide is poisonous. For the above reasons, before entering bunkers, they should be investigated for a smell of gas. If the smell of gas is noticeable, the bunker should be well ventilated before anyone is allowed to enter it. After ventilation, the bunker should be tested with a safety-lamp. The presence of gas in the bunker will be indicated by a blue cap on the yellow flame of the safety lamp, and the height of the blue increases with the percentage of gas present. An experimental safety-lamp is now being tried which has a brass bonnet surrounding the gauze. The bonnet renders the lamp safe under all conditions in explosive mixtures of gas, but it reduces the

height of the blue cap (the danger signal) of the flame. An indication of the percentage of gas in the bunker can be obtained with the bonnet of the lamp off, but the lamp must be handled by a careful man; dropping it or tilting it so the flame strikes one portion of the gauze, for any length of time, may cause an explosion. The following safety precautions are suggested:

1. Test upper portions of a bunker for gas: (a) when the bunker has been closed for longer than 60 hours; (b) when the bunker has been closed for 12 hours, if the coal is Welsh coal or any coal other than that ordinarily used.

2. If there be indication of gas, ventilate well, using fans if necessary; then retest for gas.

3. These tests should be made by a reliable man not below the grade of chief water tender.

4. Clean and inspect safety-lamps after use; a hole in the gauze makes the lamp unsafe.

5. Use only lard or sperm oil in the safety-lamps. Kerosene deposits soot on the gauze, and the deposit may glow enough to ignite the fire damp.

CHAPTER X.

LIQUID FUEL.

The term *liquid fuel* may be applied to all compounds of carbon and hydrogen which are fluid at ordinary temperatures, or which may be readily rendered fluid by the application of heat. The vegetable and animal fats and oils are not obtainable in sufficient quantities to supply the other demands upon them, and are not in use as fuels. The liquid fuels in use for boilers are as follows:

1. Mineral hydrocarbons, the chief of which is petroleum.
2. Shale oil, produced by the distillation of the bituminous shales.
3. Tar oil, a by-product in the process of the distillation of coal gas.
4. Blast-furnace oil, a similar product from blast furnaces.

The oils of the second, third and fourth classifications are scarce, and are used only in the vicinity where made.

Mineral hydrocarbons, the *petroleums,* are the only liquid fuels produced in sufficient quantity to be considered as a fuel for marine boilers. Oil fuel has superseded coal to some extent in the merchant marine and to a large extent in torpedo-boat destroyers, and is displacing coal on large men-of-war. The extent to which oil will continue to supersede coal will depend upon the somewhat doubtful continuance of its production in sufficient quantities.

The Supply of Oil Fuel.—The principal oil fields of the world are: The United States, Russia, Galicia, the Dutch East Indies, Roumania, India, Mexico, Japan, Peru, Germany, Canada and Italy. The principal fields in the United States are: Pennsylvania, Ohio, Indiana, California, Texas, Oklahoma, and Kansas.

Classes of Oils.—From the standpoint of fuel oil, there are two classes of petroleum as it comes from the well: (1) One that boils down, after successive distillations, to *paraffine;* (2) one that boils down, after successive distillations, to thick, heavy *asphaltum.*

The petroleums found in the Appalachian mountain system, in Ohio, and in Indiana, belong to the paraffine series; while those from Texas and California belong to the asphaltum series.

Properties of Petroleum.

Petroleum, as obtained from the earth, is a dark fluid, and is accompanied by hydrocarbon gases, water and earthy matter. The earthy matter is mostly salt and sand. This is *crude oil.*

Crude oil contains many series of the hydrocarbons, from those of boiling points lower than the temperatures of the atmosphere to those of high boiling points. The two principal hydrocarbon series in the petroleums are the *paraffines* and the *olefines* the first having the general formula C_nH_{2n+2}, which begins with $n=1$, giving CH_4 (marsh gas); and the second having the general formula C_nH_{2n}, which begins with $n=2$, giving C_2H_4 (olefiant gas). There are other series called the *naphthenes, benzines,* etc.

When crude oil is drawn from the earth, the gaseous hydrocarbons having a boiling point lower than the temperature of the atmosphere are given off. These gases are caught and distributed for light and power purposes in the vicinity of the wells.

After the crude oil is drawn off, it is allowed to settle, and the water and earthy matter are removed.

The members of the hydrocarbon series are gaseous for low values of n. In the paraffine series they are gaseous below $n=5$; are liquids for values of $n=5$ to 26, inclusive; and are solids when $n=27$ and above.

The boiling points increase in an arithmetical progression as n increases, the difference being about 20° C. or 68° F. for each step in the series.

Fractional Distillation.—After the water and earthy impurities are removed, the oil is sometimes subjected to what is called *fractional distillation.* The oil is placed in a still, and the temperature is raised to a certain fixed point. All of the hydrocarbons of lower boiling point are distilled off and caught in a condenser. The temperature of the still is then raised to a higher point and the distillate is caught. This method is continued until all of the more valuable distillates obtainable from that particular oil are distilled off and the residue is disposed of as liquid fuel.

The remaining oil and the distillates consist of many members of these hydrocarbon series chemically combined. In the Russian oils, the *naphthenes* predominate; in the Pennsylvania oils the *paraffines;* and in the Texas and California oils the *asphaltums.*

Fuel oil is the refuse of crude petroleum after the more volatile products have been distilled off, or it is the crude oil from the well

after the water and sediment have settled, if the flash point is sufficiently high to make it safe. The percentages of fuel oil left after the more volatile products are given off are in percentage by weight as follows:

Fuel-oil residue from Pennsylvania and Ohio oils.....	6 to 10
Fuel-oil residue from East Indian oils................	60 to 70
Fuel-oil residue from Texas and California oils......	60 to 80
Fuel-oil residue from Russian oils	50 to 60

Some crude petroleums do not yield enough of the more valuable products to pay for refining, and, having a flash point sufficiently high for use as fuel oils, are sold as such directly from the settling tanks.

It can be seen from an examination of the hydrocarbon series that the proportion of carbon to hydrogen is practically constant, and independent of the value of n. This explains why there is very little difference in the calorific value of various fuel oils. Such differences as are found to exist are generally due to the presence of small percentages of oxygen, nitrogen and mineral impurities of no calorific value.

The fractional distillates generally comprise oils as follows:

1. Light oils or petroleum spirit, gasolene, etc.
2. Illuminating oils, kerosene.
3. Lubricating oils, light and heavy.
4. The residue known as fuel oil.

In some crude oils it does not pay to carry the distillations to this extent. It may be carried past the first, second or third stage, depending upon the characteristics of the crude oil. The Pennsylvania oils are carried through the three stages, and leave only a small residue. The Texas and California oils are generally carried through the second stage, and leave a large residue. Russian crude is not distilled. It is stored in open reservoirs until it has lost its most volatile constituents. It is called *mazut*. *Naphtha* is a term applied to Russian fuel oil. It is the residue after the illuminating oils have been distilled off.

Fuel oils usually contain about 1% of moisture and from 1.5% to 4% of nitrogen, oxygen and sulphur. Some oils contain more sulphur than others.

Analyses.—The following are the analyses of the more prominent oils:

	Pennsylvania crude.	Caucasian light crude.	Caucasian heavy crude.	Russian petroleum refuse.	Texas Beaumont crude.		California Bakersfield oil.
					Before Dis.	After Dis.	
Carbon.......	84.9	86.2	86.6	87.1	84.6	83.26	85.0
Hydrogen....	13.7	13.7	12.3	11.7	10.9	12.41	13.0
Oxygen......	1.4	.1	1.1	1.2	2.87	3.83	1.0
Nitrogen.....	....	....	....	....	....	.....	0.2
Sulphur......	....	....	....	....	1.63	.50	0.8
Water.......	....	....	....	....	....	....	1.0

Physical Characteristics of Fuel Oil.

Color.—Fuel oils vary in color from greenish through brown to black. Very light brown or light green indicates a light oil, full of gas; this color is characteristic of light, unrefined oils and low-boiling distillates from paraffine-base oils. Heavy black oils are of asphaltum base.

Specific Gravity.—Their specific gravity varies from 1.025 to .749, that of water being taken as unity; and it is generally stated in terms of the Baumé scale.* The specific gravity at 60° F. can always be obtained from the Baumé degrees by the following formulæ:

When greater than unity: $\text{Specific gravity} = \dfrac{145}{145 - \text{deg. B.}}$

When less than unity: $\text{Specific gravity} = \dfrac{140}{130 + \text{deg. B.}}$

The specific gravity is a most important standard in classifying oils. Oils are rated in gravity in Baumé degrees at a temperature of 60° F. Heating the oils lightens them from 2° to 3° Baumé for every 100° F. rise in temperature.

The market fuel oil ranges from 10° to 30° Baumé.

* The density or specific gravity of oil is measured by the Baumé hydrometer. This instrument is graduated in degrees to accord with the density of a solution of common salt in water as follows: For liquids *heavier* than water, the zero of the scale is obtained by immersing in pure water; the 5° mark, by immersing in water with 5% of salt; the 10° mark, in a 10% solution, etc. For liquids *lighter* than water, the zero mark is obtained by immersing in a 10% solution of brine; the 10° mark, by immersing in pure water. After obtaining the length of a degree for liquids heavier and lighter than water, the stem of the hydrometer is graduated by measurement.

A formula in which the specific gravity in degrees Baumé is a factor was published by A. C. Sherman and A. H. Knopff, in the American Chemical Society, in October, 1908, gives the calorific value of the American petroleum oils. Formula: B. T. U.= 18,650+40 (degrees Baumé−10). This formula gives the approximate calorific power in terms of the specific gravity.

A table of the calorific values of some of the fuel oils found by this formula and checked by calorimetric determinations is given as follows:

	B. T. U. calorimeter determination.	B. T. U. calculated from formula.
Pennsylvania fuel oil	19,656	19,526
Kansas crude	19,389	19,578
Texas crude	19,242	19,332
Indian Territory	19,418	19,342
California crude	18,779	19,150
California refined	19,555	19,530

In 89% of the determinations made in the above way, the calculated values were within 1% of those found by calorimetric determinations.

The specific heat of liquid fuels is about .511. Their latent heats of evaporation are variable, averaging about one-ninth that of water, say 107.3 B. T. U.

Odor.—The fuels from particular districts and from certain refineries can be located by their odor after some experiences with the different ones. Sulphur gives to the fuel in which it is contained a characteristic odor very perceptible when the percentage is above 1.

Viscosity.—The viscosity of an oil is the rate of flow, of a certain amount, through a specific orifice at a certain temperature. The vessel in which the oil is placed is called the *viscosimeter*. In the U. S. Navy, the Engler viscosimeter is the standard. 240 c. c. of oil are placed in the cup, the temperature measured and 200 c. c. are allowed to run out. The time is noted, and comparison is made with water at 70° F.

$$\text{Viscosity at temperature used} = \frac{\text{time of flow of oil}}{\text{time of flow of water}}.$$

Viscosity falls much more rapidly with rise in temperature than does gravity.

The viscosity of fuel oils is an indication of the ease with which they will flow or be pumped; the nearer their viscosity to that of water, the greater the ease with which they can be handled.

Oils of 20° Baumé, 15 viscosity, flow rapidly with a slight head; those of 18°, or 75 viscosity, can be piped readily, but oils heavier than this and of higher viscosity require a good pressure, or heating, or both.

The viscosity of oil is the main point to consider in its proper burning. In order to have good atomization and smokeless combustion the viscosity of the oil must not be above 8 Engler, and if above 8 Engler must be reduced by heating. The use of additional heat to further lower the viscosity below 8 Engler in no way improves the evaporization. Heating an oil also aids in dissociating any water that may be in it. The capacity of a burner is increased by heating the oil up to a point called the critical; after this point is reached, additional heat lowers the capacity. This is shown in the temperature capacity curve of a burner, operating at a constant pressure, the temperature of the oil being changed, Plate XVIII.

The plate of Temperature-Viscosity curves shows the temperature-viscosity curves covering most of the oils in use for fuel.

Flash Point.—The temperature at which oils give off sufficient vapor to flash on the application of a flame or spark is called the *flash point* of the oil. It is determined in the United States naval service with the Pensky-Martens closed-cup testing apparatus. The flash point of a fuel oil is an important indication of the fuel as a carrier of lighter and low-boiling-point constituents.

A knowledge of the flash point of any liquid fuel is essential to the consideration of its suitability for use on board ship, and especially so for use on naval vessels. Fuels of a high flash point are safer than those of a low flash point.

For the tests of the flash points of different fuels to be of comparative value, they must be made in exactly the same manner. They must be tested with the same apparatus, at the same rate of heating, and the flame must be applied in exactly the same way.

The United States Naval Liquid Fuel Board, which conducted exhaustive experiments in 1904 and was responsible for most of the pioneer work in oil-burning in the United States, recommended

that no oil of lower flash point than 175° F. be used in the U. S. Navy. More recent experiments and increasing demand for oil have led to the adoption of a minimum flash point of 150° F. The minimum flash points in the several navies of the world vary from 150° F. to 248° F., while in the merchant service oils are used with flash points as low as 75° F.

Fire Point.—If a fuel oil is heated higher than the flash point, it will arrive at a temperature at which, if a flame or spark is applied to the gases, they will burn steadily. This temperature is called the *fire point.* It is generally less than 50° F. higher than the flash point, and is usually about 25° F. above it.

Notes on Storage and Transportation of Liquid Fuels.

The lighter petroleums have very pronounced searching qualities and their fumes have great penetrating power. A joint that is tight under a certain water pressure may show oil leaks at that pressure.

Oils of lower gravity, Baumé, and higher flash point will be less likely to leak, and less fumes are given off. If a joint is tight, with water under a certain pressure or head, it will be tight with the heavier oils at the same pressure.

The gases from liquid fuel oils are comparatively heavy and remain near the oil surface, or near the bottom of the tank when the tank is empty. They can be entirely freed from an empty tank only by filling it with water and washing it out until the tank is entirely free from gas.

With oil having as high a flash point as 200° F., vapors will form to a slight extent, but not in sufficient quantities to be dangerous if the tanks are tight and are properly ventilated. The nature of the ventilation depends upon the nature of the storage.

The specific gravities of oil and water being very nearly the same, the oil does not rise to the top and free itself of water very readily, unless it is heated. When heated, its specific heat is much less than that of water; therefore, it heats faster and becomes lighter. The heavier water then settles, leaving the free oil at the top. This is one of the reasons why heating coils are placed around the suction pipes in oil storage tanks.

On a vessel of great depth it has been found necessary to install a relay tank between decks, in order to avoid the great head of oil that obtains when the storage tanks are being filled. This precaution is

in addition to the pneumercator system with gages and annunciators at the booster pumps to indicate proper filling and low oil level. The side filling connections discharge oil into the relay tank through quick-closing valves. The oil flows by gravity from the relay tank to the distributing manifolds and thence into the storage tanks. Pneumercator annunciators installed at the relay tank indicate when the tanks being filled have been filled to 95 per cent capacity. The relay tank is fitted with gage glass, an overflow spring-loaded relief valve, a vent pipe connecting directly to the atmosphere, and a pipe connecting all storage tank vents so that these tanks may vent or overflow into the relay tank. No greater head of oil than given by the level in the relay tank can be placed on the storage tanks by this overflow system. Where the relay tank is installed, emergency filling connections at the vessel's side are provided, and these lead to the suction sides of the booster pumps. Proper relief valves are installed to prevent these pumps from putting a pressure on the tanks.

Fuel oil is transported in three ways, namely: (1) By pipe lines; (2) by tank cars; and (3) by tank ships or barges.

1. Pipe Lines.—Crude oil is collected into reservoirs at the oil wells. It is gathered by "gathering lines" into the "trunk lines," and is piped by these to refineries near the seaboard or to places where markets are favorable. As illustration of the extent of trunk lines, the five great oil companies operating in what is called the mid-continent field, centered about eastern Oklahoma, had 4320 miles of continuous lines in 1914, giving outlet to this field in Chicago, Ill. (and to Atlantic seaboard); Port Arthur, Texas; Baton Rouge, La.; and Sabine, Texas. The trunk lines are generally 8-inch steel pipes laid about 18 inches below the surface of the ground and are provided with heavy-duty pumping stations, generally not over 40 miles apart, which force the oil at pressures of 600 to 800 pounds.

2. Tank Cars.—This method of transporting oil is costly and is accompanied by delays, and requires the further use of barges where vessels cannot approach the fueling pier.

3. Tank Ships and Barges.—From a naval point of view this method is convenient, economical, and necessary. The tank ships may be considered as mobile bases maintaining the naval vessels upon their stations, thus requiring fewer reliefs and bringing about more effective naval effort. Tank ships are necessary for commercial purposes to transport crude oil from foreign countries and to distribute crude oil or its products to the market centers. Barges are necessary

for port loading and for port to port distribution. As indicating the importance of tank-ship construction it is stated that one-fifth of the steel-ship tonnage of this country (exclusive of that on the Great Lakes) at the close of 1917 was in the oil transportation service There were 170 steel ships. As to relative cost of transportation by the three systems, they are, in order of cheapness of fuel-oil product, pipe line, tank ship, and tank car. At some eastern seaboard points the cost of transporting fuel-oil by tank car is double that by the pipe line.

Naval interests are involved in the sources of supply, the transportation and storage of crude oil, and in the preservation of a continuing supply for years to come.

The Pneumercator.*

This is an instrument invented by a Mr. Parks, of Philadelphia, for measuring the volume or weight of a liquid in tanks or reservoirs. It does this by air pressure within a balance chamber located in the tank, the pressure being dependent upon the height of liquid above an orifice in the balance chamber and being communicated to a mercury column by a very small pipe line. The essential elements of the instrument are: (a) Balance chamber; (b) a mercury gage calibrated in feet and inches and in corresponding weights or volumes; (c) a pump or other means for supplying compressed air; and (d) a control valve (see Fig. 91).

The several positions of the control valve are: "Gage," "shut," "air," and "vent" (as indicated on the valve). At "gage," the balance chamber communicates with the gage; at "shut," all openings are closed; at "air," the balance chamber and the air pump are in communication; at "vent," the mercury column is cut off.

The installation and operation are as follows: The balance chamber is located so that its orifice is at a definite point near the tank bottom. The pipe is run to the locations where the readings are to be taken. The air pump is conveniently installed, as shown in Fig. 90. When the tank is being filled, the control valve is placed at "gage," thus permitting the gage to indicate the rise of liquid. During the process of filling the control valve should be turned to "air" so that the level of liquid within the chamber may be maintained at the orifice of the balance chamber, this level tending to rise

* From "Journal of American Society of Naval Engineers," May, 1915.

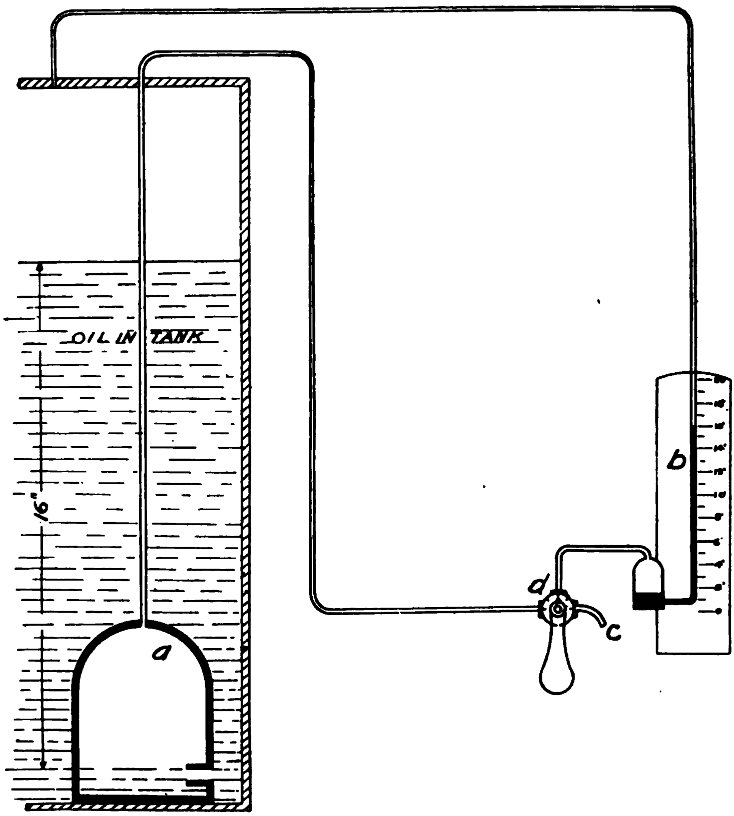


FIG. 90.

above the orifice and to cause inaccurate readings by the gage. A few strokes of the pump are necessary for this purpose. The control valve is now turned to "gage," and accurate readings are assured. A pipe is installed connecting the top of the gage mercury column with the particular tank that the gage serves. This assures accurate readings in case either pressure or vacuum exists on the tank. A duplicate column is provided for each tank at the gage board to operate the annunciator, by low-voltage electric current; this annunciator indicating "95 per cent full" and "low" levels.

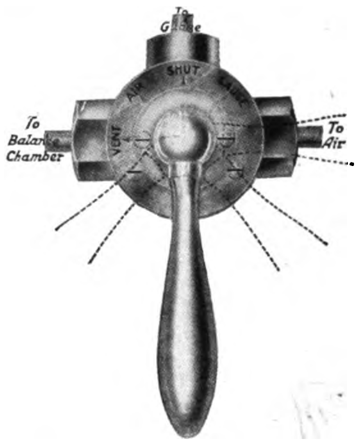


FIG. 91.—Pneumercator Control-Valve.

Comparison of the Value of Coal and Oil as Fuel.

To properly burn oil it is necessary to have a uniform steady pressure in the discharge oil spray. Several rotary and rotating plunger pumps have been designed to meet this condition.

An illustration of each is given.

Quimby Screw Pump.—The general form and construction of the Quimby screw pump is illustrated in Fig. 92. The four screws that act as pistons in propelling the water are mounted in pairs or parallel shafts, and are so arranged that in each pair the thread of the screw projects to the bottom of the space between the threads of the opposite screws. The screw threads have flat spaces and peculiarly undercut sides; the width of the face and base of the threads being one-half the pitch. The pump cylinder fits the perimeters of the threads, as shown in Fig. 92a. Space enough is

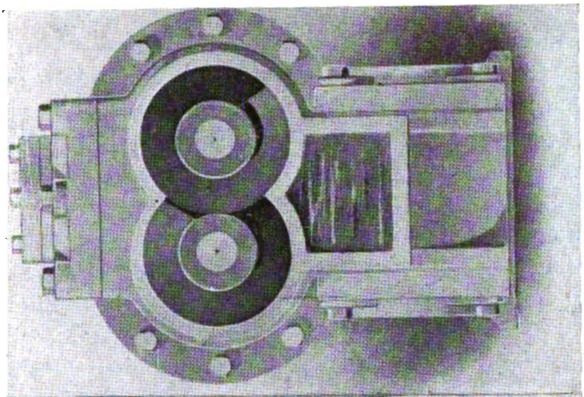


FIG. 92a.

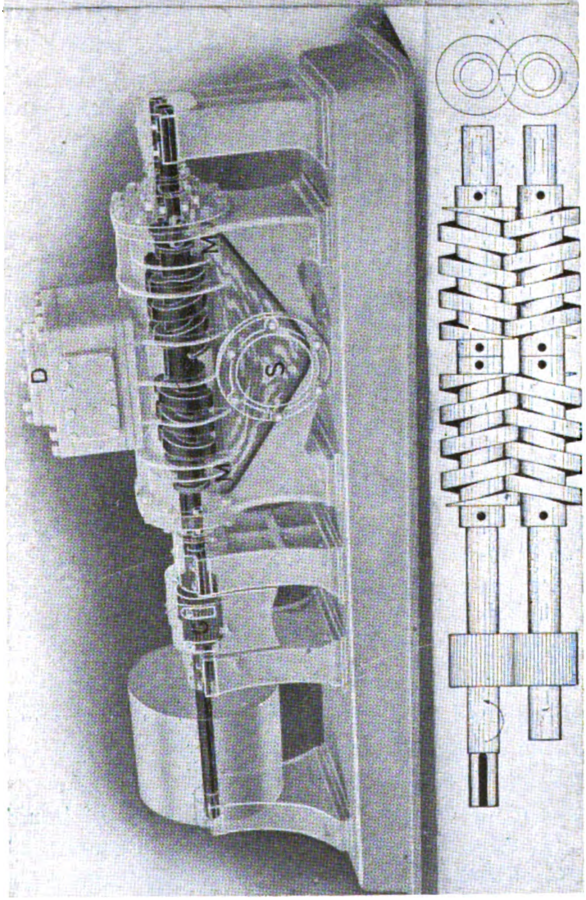


FIG. 92. Quimby Oil Pump.

left between the screws and the cylinder and between the faces of the intermeshing threads to allow a close running fit without actual contact. There is no end thrust on the screws in their bearings, because the back-pressure of the column of liquid is delivered to the middle of the cylinder and the endwise pressure upon the screws in one direction is exactly counterbalanced by a like pressure in the opposite direction.

The suction connection is shown at *S*, Fig. 92, and opens into a chamber underneath the pump cylinder. The suction liquid passes through this chamber to the two ends, and is forced toward the center by the action of the two pairs of intermeshing threads; the discharge being in the middle of the top of the cylinder, as shown at *D*. The power to drive the pump is applied to one of the shafts, and the second shaft is driven by means of a pair of gears, shown at *G*, Fig. 92.

The pump has no internal packing, no valves, and no small moving parts. The only packing is in the stuffing boxes, where the two shafts pass through the cylinder heads. As these stuffing boxes are on the suction of the pump, there is no tendency to blow out the packing.

Kinney Pump.—The general form and construction of the Kinney pump is illustrated in Fig. 93. The pump consists of a body *B*, a pump plunger *D*, placed eccentrically on a shaft *C*.

The operation of the pump is as follows: The shaft rotates in the direction shown by the arrow. Oil enters at *F* into cavity *H*. As *D* revolves oil is forced around, through port *E*, and out at *G*.

Plate XVIIIa is a line sketch showing the oil piping arrangement of a large oil-burning ship. Oil is drawn from tanks either forward or aft through manifolds by the booster pump. It is then picked up by the service pump and forced through the heaters to the boilers. Separate pipe lines are run from manifolds to the hand pumps which discharge through suitable connections to boiler service lines.

Theoretically, good coal evaporates 14.66 pounds of water per pound of coal, and good liquid fuel 19.9 pounds per pound. Theoretically, the calorific value of 1 pound of liquid fuel is 1.36 times the calorific value of 1 pound of coal.

A barrel of oil contains 42 gallons; a barrel of liquid fuel 16° Baumé gravity, or .959 specific gravity, would contain 336 pounds, or 1 barrel of such oil would equal in calorific value 456.96 pounds

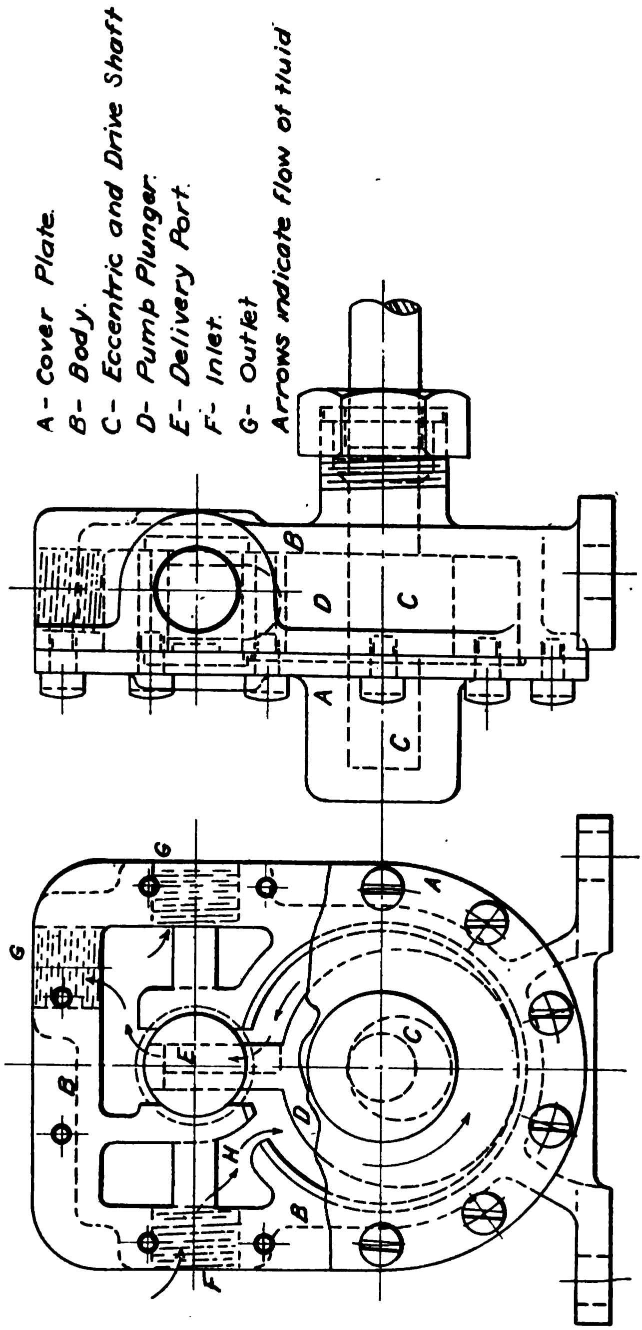


FIG. 93.—Kinney Pump.

of good coal. 4.9 barrels of oil would equal 1 ton of coal.

One ton of coal occupies about 43.5 cubic feet and 1 ton of oil about 39 cubic feet.

If the same space could be used for oil that is used for coal, 1.1154 times as many tons of fuel oil could be carried as coal, and this fuel would contain 1.517 times as many heat units as the coal.

If the boiler efficiency remained the same with liquid fuel as it is with coal, the steaming radius of that vessel would be increased 1.517 times with liquid fuel.

Boiler Efficiency.—The boiler efficiency with liquid fuel is higher than with coal, for the following reasons:

1. Liquid fuel can be completely burned with less excess of air than coal, thereby giving a lower loss in chimney gases.
2. There are practically no losses from waste of fuel, as there are with coal.
3. The air supply and oil supply to the furnace can be kept constant, giving a constant rate of combustion with a constant furnace temperature, which cannot be maintained with coal.
4. The boiler heating surfaces remain clean with oil.

Therefore, the actual increase of steaming radius would be between 1½ and 2 with liquid fuel over coal for the same speeds.

Reduction in Fire-room Force.—As there is no handling of coal or working of fires, the number of firemen and coal passers can be greatly reduced. A coal-burning battleship having a complement of 220 firemen and coal passers could, with oil fuel, have that complement reduced to about 50, which would be enough for operating, cleaning and repair purposes. The saving in pay and rations would be considerable, and the space now taken up for wash-rooms and lockers would be available for the remainder of the crew.

Rapidity of Getting the Fuel Aboard.—Coaling a battleship requires from one to two days, with another day for cleaning ship, and it is an "all-hands" job. With oil fuel a ship can be fueled in 5 or 6 hours, and it takes only a few men to do the work. A ship can easily be supplied with oil at sea, and the steaming radius of a ship is limited only by the amount of oil fuel in the fuel ships, as it would not require an entry into port for replenishing the supply.

Oil More Efficient.—The excess of air, that comes with opening the doors for firing and cleaning fires when using coal, is avoided when using oil. As the pressure of air and oil can be regulated, it is possible to get better economy from oil firing, as the proportion of air for combustion is under control. More perfect combustion prevents formation of residuals and smoke, resulting in cleaner and more efficient heating surfaces. There is but little waste of fuel on starting up or shutting down.

Storage of Oil.—Portions of a ship now useless for coal bunkers, through their narrowness or inaccessibility, are available for oil

storage. The double bottoms are used as oil tanks, and this feature can be taken advantage of in trimming the ship.

Advantages of Liquid Fuel for Marine Use.—1. Greater boiler efficiency.

2. Fewer men required in the fire-room force.

3. Fewer weights to carry, such as firing tools, ash engines, buckets, etc.

4. Clean boilers on the fire sides at all times.

5. No fires to clean, no ashes to remove; therefore, greater fuel economy.

6. Greater ease and cleanliness with which, and less time in which, it can be got on board and stowed in storage tanks, both in port and at sea.

7. Less time in getting up steam.

8. Steam can be controlled more easily.

9. Practically no loss in getting up steam, standing by and coming to anchor.

10. More fuel can be carried in the same space. It can also be carried in spaces that are waste spaces, such as double-bottom compartments and other isolated compartments, where coal cannot be carried.

11. Less wear and tear on the boilers.

12. Reduction in the length of the fire-room, as there is no space required to work the fires.

Disadvantages of Liquid Fuel for Marine Use.—1. Greater cost.

2. Requires more care in handling to prevent fire and explosions.

3. The supply is not general at present.

4. Structural difficulties in connection with its safe and satisfactory storage.

Combustion of Oil Fuel.

The general principles of the combustion of fuel already discussed apply to oil as well as to coal. The essential difference between the burning of oil and the burning of coal lies in the greater ease with which theoretically perfect conditions can be realized with the former. The factors of high furnace temperature, sufficient quantity of air and ample combustion space assume greater importance with fuel oil than with coal; but at the same time, these factors are handled with much greater facility in an oil-burning boiler than in one burning coal.

For the complete combustion of fuel oil, the requisite conditions are: (1) The oil must be broken up into minute particles (atomized) and sprayed from a burner before it is ignited; (2) the gases must be kept at the ignition temperature long enough to insure burning; (3) the air supply must be in sufficient quantity and of sufficient velocity to surround completely every minute particle of of oil and cause its complete combustion to CO_2 and H_2O.

The first condition is fulfilled by the use of atomizing burners previously described. The fineness of the atomization depends upon the pressure of the oil, the temperature of the oil, and the design of the burner atomizing head. If the pressure and temperature of the oil are too low, the particles of oil may be too large for complete combustion, and some of the oil will then be deposited on the heating surfaces and furnace lining as soot and unburned carbon.

The second condition is fulfilled by having a large combustion space (furnace) with a thick brick lining on the bottom and sides. The large combustion space permits the gases to diffuse and the air to circulate around them, and retards the gases long enough to burn them completely before they strike the cool tubes. The brick lining, when once heated, retains the heat and keeps the furnace temperature high in somewhat the same manner as the incandescent bed of coal in a coal-burning boiler. The bricks must be of the highest quality, and should be capable of withstanding a temperature of 3200° F.

The third condition is fulfilled by regulating the quantity and velocity of the air in the furnace by means of forced-draft blowers and adjustable air registers. By regulating the speed of the blower and adjusting the shutter of the air register, the velocity of the air is made high enough to overtake and surround every particle of oil in sufficient quantity to burn it completely. At the same time, the air is given a whirling motion, so that it will mix more intimately with the gases and oil spray and not pass into the furnace in streams.

Practical Methods of Approaching theoretically Perfect Conditions in Burning Oil.

Proper Atomization.—With the present fuel-oil installations in the U. S. Navy, a pressure of the oil in the burner of from 150 to 200 pounds per square inch is required for proper atomization. At the Fuel-Oil Testing Plant in Philadelphia, a standard pressure of 200 pounds is maintained on all burners; and when it is necessary

to reduce the rate of combustion, some burners are cut out. If the burner is clogged with dirt or gum, or if the outlet hole in the tip is scored, the atomization will not be good. If the hole in the tip is increased slightly in diameter, there will be a great increase in the quantity of oil discharged. The opening in the navy standard burner is only $\frac{3}{64}''$ in diameter. For use in port, burners of smaller capacity (smaller outlet holes in the tips) are supplied.

Unless the viscosity of the oil is reduced to the proper point, the atomization will be improper, or *nil,* no matter how perfect the burner and how proper the pressure. With the oils now in use, it has been found, as previously stated, that the temperature must be raised enough to lower the viscosity to 8 on the Engler scale to insure proper atomization and smokeless combustion of the oil. Larger heaters are required for oils of high viscosity than for those of low viscosity. The heaters in general use in the U. S. Navy will reduce the viscosity to 8 if the viscosity is not greater than 200 at 100° F.

Another point in connection with viscosity is that it must be reduced enough for the oil service pump to lift the oil and force it through the piping at a certain rate. With most of the fuel oil that has been used, it is generally not necessary to heat the oil in the storage tanks to pump it. Some oils, however, are too thick to flow freely enough to be pumped at ordinary temperatures, and have to be heated. Steam coils around the suction pipes in the oil tanks accomplish this purpose. It has been found by experiment that it is not necessary to heat any known oil above 105° F. to insure that the pumps will give sufficient supply for full power. If oils of higher viscosity are discovered and come into use, more heating will be necessary and change in the types of heaters and pumps may be desirable.

Rotary pumps are best suited to maintain steady pressures at the burners. With the reciprocating pumps in general use, a steady pressure is maintained by means of oil service-pump governors, by relief valves on the pump, and by air chambers on the dead ends of the oil service-pump discharge line to the burners. Oil absorbs the air in these chambers, and in practice it is necessary to re-charge them to a pressure of 90 pounds per square inch about twice a day in order to prevent fluctuations in the oil pressure and vibration of the oil pipes.

Keeping the Gases at the Proper Ignition Temperature.—Once the brick lining of the furnace is thoroughly heated, the furnace remains hot. Bricks must be secured from jarring loose by vibration, the boiler casing must be kept air-tight (except through the registers), and the air supply must be kept as low as is consistent with economical combustion. The cone of oil particles sprayed from the burner should not strike the relatively cool water-containing parts of the boiler, for the oil spray would then be cooled below ignition temperature and, also, dangerous local overheating of the places of impact might result. The burners should be so placed in the registers as to secure the proper direction of the spray. If bricks are burnt up or jarred loose the furnace will cool and the casing may warp. The harmful effect of cold air leaking through the casing is due not so much to the cooling effect on the furnace as to the decrease in efficiency of the heating surface on account of the low conductivity of this excess air.

Proper Quantity and Velocity of Air.—The proper quantity and velocity of air are regulated by the blowers and by the shutters on the air registers. The quantity of air actually in the furnace may be sufficient for complete combustion, but there may not be enough movement to this air to supply more oxygen as some of the oxygen is consumed. (See chapter on "Combustion.") Hence, the air must be supplied fast enough to furnish the necessary oxygen. Therefore, the *velocity* of the air is the most important factor in its supply to the furnace. *The quantity of air is sufficient when the flame of the oil is short, and yellowish-white. In the furnace, little flame is apparent; the gases of combustion are colorless, and the lines of division among the bricks in the back wall can just be made out. There is then proper combustion.* If the flame is pure white, and the back walls can be seen distinctly through it, there is an excess of air. If the flame is dark yellowish-red, there is insufficient air.

Too much air gives white smoke from the smoke-pipe. Too little air gives black smoke. The quantity of air is about right when the smoke is a light brownish-gray haze—just a feather of smoke. With nearly all registers in use, it is desirable to run with the shutters partly closed, as this gives better regulation of the velocity of the air. The amount of opening varies with the rate of combustion and the type of register.

Insufficient air causes vibration or panting of the boiler casing and lining, and knocks down the brick-work. The vibration is due

to some of the unconsumed oil dropping to the bottom of the furnace and later forming explosive mixtures. If vibration occurs, the blower should be speeded up until it ceases, or else some burners should be cut out.

While the color of the smoke and the flame is an excellent indication of proper combustion, the only *sure* indication is an analysis by some gas apparatus such as the *Orsatt.*

The position of the burner in the air register must always be such that the spray will clear the brick lining surrounding the opening in the casing for the register, and in addition it should be further adjusted to get the best combustion with varying rates of power. The burners fitted with impeller plates should have the tips about 1″ in front of the plate for ordinary powers and about 2″ in front for full power.

Operation of Oil-Burning Boilers.

Oil-burning boilers are normally operated, particularly at sea, under forced draft, using the closed fire-room system except in some battleships in port where the open fire-room system is used There is no prescribed limit to the air pressure, but between 6″ and 7″ of water is necessary for full power.

In port, the practice varies. All three methods—mechanical atomization, air atomization and steam atomization—are used. Sufficient data are not available to determine the relative merits of the several systems at the low rates of combustion required, but the tendency is toward mechanical atomization, with an occasional use of the forced-draft blowers in connection with it.

Air atomization has the disadvantage of requiring heavy air compressors in conjunction with it, wear and tear on these compressors, and extra steam to operate them.

Steam atomization has the disadvantage of waste of steam and the probability of the burners going out due to wet steam, with the resultant danger from a flare-back when the burner is re-lighted.

To Start a Boiler—No Steam Available.—Make all necessary examinations and tests as to water, fittings, etc., required for all boilers; then:

1. Take off stack cover.
2. Open damper (if fitted).

3. Examine furnace to see whether any oil has dropped from a leaky burner. If so, wipe it up.

4. By means of the hand pump, bring up the pressure on the burner line to about 200 pounds per square inch, and keep it as steady as possible.

5. Open wide the shutters to all registers to give as much air as possible.

6. Dip a torch made of a long rod, with asbestos ball wicking or waste on its hooked end, into a can of oil or kerosene, and light the torch.

7. Open the burner and light it, and keep the pump going constantly.

8. Unless the oil is a light one whose viscosity is 8 or below at 70° F., the torch will have to be kept up to the burner constantly until steam forms and the viscosity is reduced by heat to 8 or below, when the torch may be withdrawn.

9. When steam has reached 75 or 100 pounds, put steam on the oil pumps and heaters and cut out the hand pump.

10. Put steam on the forced-draft blower and get ready to light other burners.

11. Start blower slowly and light off burners.

12. As soon as the burner is lighted, speed up the blower until the air pressure is sufficient to prevent vibration and flare-back.

13. Close the shutter of the register to the proper opening (determined by experiment with the particular plant concerned).

If it is desired to prevent smoke, an excess of air will be needed until the furnace is well heated, when the proper quantity of air may be obtained by closing the registers the proper amount.

If additional burners are required, adjust the air register for that burner to the proper opening, speed up the blower, and then light off the burner. If vibration results, cut out a burner until the blower can be speeded up enough to give sufficient air.

Keep a half glass of water. If the water level is too high, the boiler will prime.

As burners are added to a boiler, the water level rises, and *vice versa.* Never cut out all the burners at one time on a boiler operating at full speed. The water level will drop out of sight, and, if the oil being used is a heavy one, the relief valve on the oil pump may

stick and the high pressure in the oil line may rupture the pipe and cause a dangerous fire.

General Notes on Lighting Boilers.—If steam is available, start the blower and turn it over slowly to prevent any danger of flare-backs. Hold the torch to the wide-open vanes of the register, and open the burner valve wide. When the burner is lighted, regulate the shutter opening and speed up the blower to eliminate smoke. Always light off the top center burner first, and then the adjacent burners in order, wing burners last. Warm up with two burners, and, if any more are desired, cut them in as necessary. If a burner is lighted under a boiler, other burners may be switched on without using a torch. Never try to light a burner from a red-hot back wall, as there is danger of a flare-back. When there is any blazing oil on the furnace floor, keep the blower turning over slowly to clear the furnace of gases before trying to relight a burner. When using only a few burners, use the center burners of the top row.

Full-power Conditions.—Running at full power with oil-burning boilers differs from running at lower powers only in so far as it is necessary to increase the oil pressure, maintain a high air pressure, and use as many burners as possible.

Shutting down a Boiler.—1. Shut off burners one at a time, wing burners first, then the bottom row, then the upper rows, and the top center burner last.

2. Slow burners first before cutting out.
3. Slow fuel-oil service pump.
4. When all burners are shut off, close off oil supply.
5. Close all air doors.
6. Stop blower when it is certain that it has run long enough to blow all oil gas out of the boiler.
7. Put on smoke-pipe cover.

Oil as an Auxiliary to Coal.

A few battleships in the U. S. Navy are fitted to burn oil in conjunction with coal. The installations for burning the oil, which are of a permanent nature, consist of the usual pumps, storage tanks, etc.; there is a material decrease in the number of oil burners per boiler, the number of burners per boiler, on a battleship, being from three to eight.

The original idea, in fitting these ships to burn coal and oil simultaneously, was that, in case of dirty fires, the oil fuel would aid in making temporary increases in speed. Such, however, has not proved to be true in practice, and the principal advantage of the double system is that more fuel can be carried by the ship, as oil can be stored in places not accessible for coal storage, and, by burning oil alone strategical advantages may be gained on account of the greater steaming radius obtained.

Some disadvantages of combining oil and coal as fuel are: (1) The combustion chambers are too small to burn the oil and coal together in an efficient manner; (2) the coal fire cannot be properly tended when burning oil, as the flame shuts off a view of the top of the fire; (3) the use of oil causes the clinker to fuse on the grate. making the fires very hard to clean; (4) it is a difficult matter to carry such pressures as will give the proper volume and velocity of air necessary for economical combustion, and it is impracticable properly to supply the requisite air to burn the oil sprayed above the coal fire on the grate; (5) the high fire-room air pressures necessary to give the proper velocity and volume would be injurious to boilers designed essentially for coal burning; (6) it is necessary to carry a complete outfit for each kind of firing.

Special Notes in Regard to Fuel-Oil Installations.

Dangers of the Oil-Burning System.—There are three principal dangers that may arise in an oil-fuel plant. (1) *Flare-backs;* (2) *fires;* (3) *leak of oil to steam side of heaters and thence to boilers.*

Flare-backs are due to explosions of a mixture of oil gas and air in the furnaces. These generally occur at the time of lighting fires, and may result in serious injury to the fireman by burning; in addition, the brick-work may be damaged and the boiler be put out of commission by the force of the explosion. The precautions necessary to prevent flare-backs are as follows:

1. The furnace floors and any pockets in the boiler casing where oil can collect must be kept scrupulously clean and free from oil.
2. There must be no leaks from the burners into the furnace.
3. When lighting fires, the pressure in the oil service pipes must be high enough to atomize the oil completely as it leaves the burner, to insure that oil does not drip onto the furnace floor.
4. If there is steam on the ship, the blowers must be running at the time the burner is lighted, giving a pressure sufficient to clear the furnace of any oil gas that may be in it.

5. The fireman must use a long torch (at least 4 feet) in lighting a burner on a cold boiler, to insure that, in case a flare-back does occur, he will not be burned.

Fires may be caused by the ignition of oil or oil gases in any place where oil accumulates by leakage from the system. Absolutely tight joints, with no leakage of oil, are necessary for safety; this must be impressed on everyone; and leaks, when discovered, must be stopped immediately. Before using any part of an oil-fuel system, it should be tested to a pressure of 300 pounds with cold oil and be proved to be tight.

Oil spilled anywhere must be immediately wiped up.

A box of sand should be kept in each fire-room to put out any oil fire.

Gage glasses on oil tanks should be shut off except when readings are being taken.

Fire extinguishers should be kept in fire-rooms, and a steam hose should be kept ready.

Bilges should be inspected frequently for any collection of oil.

It is a good practice to close the fire-rooms and run the blowers for a few minutes every day in order to expel any gases which may have accumulated in inaccessible places or around undiscovered leaks.

Keep paint-work to a minimum; *i. e.*, the boiler casings, pump barrels and everything else that can be kept bright should be so kept. On destroyers, the frames and plates in the boiler compartments are galvanized; therefore, no paint is necessary; but a careful watch must be kept to prevent corrosion where the frames or plates become exposed when the galvanizing wash is knocked off.

Leaks of fuel oil into the feed-water system will occur whenever the pressure oil heaters leak and the oil pressure is greater than that of the steam.

These leaks are detected by an examination of the water drained from the steam side of the heaters. When such a leak is discovered, the heaters are shut off and the oil is bypassed around them.

Care of Burners.—Burners and burner tips, when not in use, should be kept covered with a thin coating of light engine oil.

Before new burners are used, they should be tested out under water pressure and the cone of spray should be carefully examined for streaks. The streaks are caused by irregularities on either the inside or the outside of the orifice, and should be eliminated by

polishing before the burner is used. If the streaks are not eliminated, an excess of air will probably be needed to run smokelessly. A stick of hard wood inserted into the orifice with a paste of oil and finely powdered glass will remove the streaks. Old tips should be periodically tested under water pressure, and should be replaced with new tips if badly worn.

If, while under way, some burners are found to leak considerably, it is better to reduce the oil pressure and light more burners.

Dirty burners cause smoke.

Furnace Brick-work.—Extra good quality bricks and special high-heat cements must be used in the furnaces of oil-burning boilers. The joints between the bricks must be very carefully made, and the cement which protrudes from the joint must be smoothed back an inch or so from the joint, so that the sharp edges of the brick will not be exposed to the erosive action of the heat. The cement is first thinly spread over the entire surface of the brick, and, when the bricks are brought together, all air is expelled from the joint. When all brick-work is laid up, the entire surface of the furnace lining should be coated with a thin mixture of the cement, about the consistency of paint. The life of the brick-work is limited by the life of the joints.

Bricks are bolted to the boiler casing, and the bolt holes on the inside are filled with cement. The best recent practice is to extend the bolts only part way into the brick-work (see description of B. & W. boiler, Chap. III).

Air leaks.—It cannot be repeated too often that boiler casings *must be tight* for efficient steaming. Dead boilers in the same fire-room with steaming boilers must have all doors in their casings closed and must not leak. Air leaks not only reduce economy and injure steaming boilers, but also waste steam by necessitating an increase in the air pressure delivered by the blowers.

Dangers from Use of Liquid Fuel.

The dangers from the use of liquid fuel on board of naval vessels are very few: (1) If the tanks, piping and fittings are properly prepared and are thereafter kept in proper condition; (2) if the fuel supplied has a flash point of 150° F. or above; and (3) if the fuel is never heated above a temperature of 10° below the flash point until it leaves the burner; (4) if the fuel, wherever spilled or

allowed to overflow into bilges, is immediately cleaned up and the place is covered over with sand.

The vapors from petroleum are explosive when mixed with the proper proportion of air, and are non-life supporting. Therefore, no one should ever enter a tank until the vapors have been blown out with steam or air; never without a life line around his body, nor without being attended by others on the outside; and never under any circumstances with an open light

Fuel oil containing no sulphur or moisture will cause no corrosion or decay metals, pipes or brick-work, but will rot rubber, fabrics, concrete and paints. The amount of sulphur sufficient in oil to produce appreciable corrosion of the oil storage tanks has not been definitely determined. It is known that some oils containing as much as 4½% have been carried in steel tanks without any evidence of corrosion.

Smoke Screen.—An important advantage of the use of oil fuel is the ability to make a smoke screen. This is done by reducing the amount of air supplied while the oil supply is kept constant. In practice a smoke screen is made by slowing the forced draft blower.

NOTE.—For additional information on liquid fuel, see Chapter XIV and Appendix.

CHAPTER XI.

FIRING.

Precautions Prior to Lighting Fires.—Preliminary to lighting fires in any marine boiler, using either coal or liquid fuel, the precautions that must always be taken are:

1. There must be water in the boiler above the highest heating surface; the water should show in the gage glass for about one-quarter of its height.

2. The gage-glass cocks should be tried and put in proper condition if the gage glasses do not register correctly.

3. The gage cocks should be tried and proved to be working properly.

4. The bottom and surface blow valves should be closed, and all connections to the boiler should be examined and proved to be properly secured and ready for use.

5. The smoke-pipe covers should be removed.

6. The dampers to all idle boilers that connect through the breeching to a smoke-pipe in use should be closed tight.

7. The smoke-pipe guys should be examined and, if set up taut, they should be slacked off evenly all round.

8. All connection and dusting doors on the boiler must be closed and properly secured.

9. The air cock on top of the boiler should be open.

10. All cocks or valves on the line of steam to steam gage must be opened.

11. The safety-valve hand-lifting gear should be operated to see that the valve is not stuck on its seat.

On naval vessels, the engineer officer is generally given about 24 hours notice as to the hour set for sailing; the speed that will be required; the destination of the vessel; and the probable nature of the steaming required; whether the vessel is to steam singly or in fleet, and if in fleet whether maneuvering is to take place.

When steaming in company with other vessels, the senior officer present sets the "standard speed" and all vessels must have steam enough to keep distance on the flagship and enough more to give them "full speed" for a short time.

In fleet work, the standard speed having been set in the sailing orders, it is customary to get up steam in enough boilers to make, steadily, about two knots more than the standard speed.

After getting his orders, the engineer officer knows from experience, or by consulting the log book, steaming trial data or the engineer's note book, the number of boilers necessary to meet the requirements.

Starting Fires and Getting up Steam in a Coal-Burning Boiler.—After the steaming orders are given to the engineer officer, he decides on the boilers to be used, generally using those that have been under steam the least since commissioning the vessel, unless there are good reasons to the contrary. He then orders these boilers primed and fires started at a certain time to have steam up to working pressure, safety valves tested and engines warmed up and turned over with steam at about 30 minutes before the time set for getting under way.

With fire-tube boilers it requires at least 6 hours to form steam and get it up to working pressure, without risk to the boiler; with water-tube boilers 3 hours are usually allowed, although steam can be raised in 50 minutes from the time fires are started, without much risk to the boiler.

With fire-tube boilers in which hydrokineters are fitted, they are turned on 8 or 10 hours before fires are started and are kept on until steam is up to working pressure. A hydrokineter is an injector for circulating water in a large Scotch boiler. If fire-tube boilers are not fitted with hydrokineters, the auxiliary feed pumps are started at the same time as the fires, taking their suctions from the bottom blow-valve connections to the boiler and discharging into it through the auxiliary-feed check valve, thereby circulating the water in the boiler and allowing it to warm up gradually and evenly all over; the pumps should be run until steam forms.

Fires are started in time to have steam up to working pressure, safety valves tested with steam and all boilers connected to the main and auxiliary steam lines at least 1 hour before time set to get under way; this allows an hour for completely warming up the engines and trying them with steam, and, barring unforeseen accidents, assures being ready in every respect to get under way at the time set.

Priming Furnaces.—If there is a boiler in use from which live coals can be obtained, the priming of a furnace consists in spreading a light layer of coal over the grates. If there is no boiler in

use the grate in front of the furnace door is covered with wood and oily waste, in addition to the coal spread over the grate. All of the above preliminary precautions having been taken, fires are started by placing burning coal from a boiler in use in the front of the coal-primed furnace, or by lighting the wood and oily waste at the front of the grate. The dampers are now opened, the furnace doors are opened slightly, and the ash-pan doors are closed. The fire will gradually work its way back over the whole of the grate and, as this occurs, more coal is added and the fire is gradually built up to the proper height. The fires may be hurried by opening the ash pan and closing the furnace doors; they can be checked by closing the damper and the ash-pan doors.

As the water in the boiler warms up, the level will rise and air will escape from the air cock and from the drain cock on the steam gage. When steam forms and can be seen blowing out of the drain to the steam gage, this drain cock and the air cock on the boiler are closed and pressure begins to show on the steam gage. If the gage does not immediately begin to register a pressure, all of its connections should be examined and the reason for not registering be ascertained.

Steam pressure now rises slowly and gradually, and the pressure is allowed to run up until the safety valves are blown with steam; the pressures at which they blow are recorded; the damper and ash-pan doors are closed and the steam pressure is allowed to fall to a few pounds above that in the main and auxiliary steam lines.

Connecting Boilers to Main and Auxiliary Steam Lines.—When there are independent main and auxiliary steam-line valves on the boiler and steam is on both of these lines, a boiler is connected to them when the boiler pressure is a few pounds higher than the steam in the line. If there is no steam in either of these lines, the lines are drained, drains to traps are left open, traps are bypassed, and the valve on the boiler is opened very slightly, allowing the steam line to warm up gradually and the pressure in it to rise slowly until the pressures in the boiler and the line equalize; the boiler stop valve can then be opened the proper amount and the bypasses on the traps be closed. After one boiler is connected to the main and auxiliary lines, the others are connected when their pressures are a few pounds higher than those in the lines.

In connecting a boiler to the auxiliary or main steam line, the valve should be just moved off its seat until the pressures in the

line and boiler equalize. If this is not done, serious water-hammer in the pipes may result, causing leaks in the pipe line, or rupture in the pipes. When the boilers connect to the auxiliary line only, and through it to the main line by communicating valves, all boilers are connected to the auxiliary line, as stated above. The communicating valves between the main and auxiliary lines, or bypasses around them where fitted, are then opened slightly until pressures equalize in the lines, when the communicating valves can be opened the required amount.

In boiler management a thorough knowledge of the main and auxiliary steam lines, their valves, drains and other connections is absolutely necessary; and extreme care should always be taken to connect a boiler with any line only when the pressure in the boiler is nearly the same as that in the line, and then only by slightly opening (cracking) the valve until the pressures have equalized, before fully opening the valve. When turning steam from a boiler into any line, the drain valves on that line must be open, and the traps should be bypassed until the steam line is warmed up.

Some superheaters are fitted, without drains, and in such position that water accumulates in them by condensation after boilers are disconnected. In such cases, when the volume of steam in the steam pipes is adequate, the connecting valves may be opened slightly when the boiler pressure is a few pounds below the pressure in the steam lines. Then steam passing from the line, through the superheater, into the boiler, will blow the water from superheater back into the boiler. The stop valves are then closed again, and the boiler safety valves are tested. This procedure prevents carrying the water in the superheater over into the steam line, as would be the case were the boiler stop valves opened when the boiler pressure had been raised a little above the pressure in the steam line.

Warming up the Engines.—Steam for warming up the main engines is taken from the auxiliary steam line through the cross-connection to the main steam line.

Steam should form on all boilers at about the same time; shortly thereafter, the throttle valves are closed and steam from either the main or auxiliary lines is turned into the cylinder jackets.

Water-tube boilers, as a rule, have only one steam connection, that to the auxiliary steam line, the auxiliary line connecting to the main line by communicating valves; therefore, the second method can be used only on a very few of the older vessels.

With large engines, steam should be on the jackets and the engines should be warmed for at least 1 hour before they are moved with steam.

Large turbines are warmed by turning steam into them, opening their drains and revolving the rotor with the turning engine, with no vacuum in the condensers. Some turbines are started cold. The time of warming up is variable.

Controlling the Steam.—Formerly, when preparing to get under way, when coming to anchor or when standing by, steam pressures were controlled principally by means of the *bleeders,* which are bypasses from the main steam lines to the condensers. This practice has been proven to be injurious to the condensers, and therefore the present practice is to regulate or close the ash-pan doors and to further decrease the draft by using the dampers. Opening the furnace doors will check the production of steam; but this is likely to damage the boiler, as the cold air currents thus admitted cause unequal expansion, and such practice is forbidden. Throwing green coal on the fire will also check the steam production for a short period of time. Much of this coal is wasted, however, and it also builds up a heavy fire; so this method is no longer used. The ash-pan doors must be regulated with much care to avoid burning out the grate bars.

When steaming in fleet, the steam pressures in fire-tube boilers are more easily controlled than those of water-tube boilers. The reason for this is that there is in the fire-tube boiler a much larger relative volume of water heated to the working pressure temperature than in the water-tube boiler. With a water-tube boiler a slight increase in the demand for steam causes the pressure to drop more quickly than the same increased demand would with a fire-tube boiler. Therefore, more care is required in controlling the steam; and in steaming in fleet where the speed is varying from time to time, team work is required between the machinist at the throttle and the water tender in the fire-room. The steam pressure falls more quickly on an increased demand for steam; it also rises more quickly when the demand for steam is decreased.

Methods of Firing with Coal.

Mechanical Stoker.—The ideal method of firing coal is the one in which the mechanical stoker is used. The mechanical stoker provides a more regular rate of supplying coal to the furnace and

avoids the fluctuations of furnace temperatures caused by the opening of furnace doors when firing by hand. The rate of combustion and the furnace temperatures are, therefore, more nearly constant than can be maintained with the most methodical hand firing. The mechanical stoker is also more economical in the use of coal and in labor than hand firing. While there are many successful mechanical stokers in use under shore boilers, the mechanical difficulties of fitting and operating them under marine boilers are so great that they are not used. Some of these difficulties are:

1. The spaces available for marine boilers are too small and too congested to allow proper installation of mechanical stokers.

2. The motion of the vessel in a heavy sea has been found to prevent their operating properly.

3. The rate of feed cannot be varied sufficiently to satisfactorily meet the requirements of naval vessels, with their great variations in rates of combustion.

Hand firing is the only method now in general use for marine boilers. Naval boilers are not designed to get the maximum economy in the use of coal; they are designed more with the view to get the maximum amount of steam possible per unit of weight. They have small furnace volumes, and are installed in contracted spaces. The difficulties of firing properly are great; the coal is burned in a furnace space of contracted dimensions, so that the gases of combustion come in contact with the heating surfaces, and are cooled below their ignition temperatures, before all of the combustible matter in them has been totally consumed. Smoke and loss of economy increase as the percentage of volatile matter in the coals increase.

The best way to explain the difficulties of obtaining high economy, with the ordinary furnace, from the bituminous coals when hand-fired, is to give the sequence of events that take place between two successive firings. When it becomes necessary to throw more coal on the grate, there is already on it an incandescent bed of coke, say 6″ to 8″ deep. When firing, a few shovelfuls of coal, much of it of fine size, is spread evenly over the bed of coke. The first thing the fine coal does is to choke the air spaces existing throughout the bed of coke, shutting off the air supply, which is needed for burning the gases from the fresh coal. The next thing is a very rapid evaporation of moisture from the coal, a chilling process which robs the furnace of heat. Next is the formation of

water gas by the chemical reaction, $C+H_2O=CO+2H$, the steam being decomposed, its oxygen burning the carbon of the coal to carbonic oxide, and the hydrogen being liberated. This action takes place when steam is brought in contact with highly heated carbon. This is also a chilling process, absorbing heat from the furnace. The two valuable fuel gases thus generated would give back all the heat absorbed in their formation, if they could be burned, but there is not enough air in the furnace to burn them. Admitting extra air through the fire door at this time will not accomplish the purpose, for the gases being comparatively cool cannot be burned unless the air is highly heated. After all of the moisture has been driven off from the coal, the distillation of the hydrocarbons begins, and a considerable portion of them escapes unburned, owing to the deficiency of hot air, and to their being chilled by the relatively cool heating surfaces of the boiler with which they come in contact. During all of this time smoke is escaping from the smoke pipe, together with unburned hydrogen, hydrocarbons and carbonic oxide, all fuel gases; while at the same time soot is being deposited on the heating surfaces, thereby diminishing their efficiency in transmitting heat to the water.

At length the distillation of the hydrocarbons proceeds at a slower rate, the very fine coal which at first obstructed the air supply is partially burned away, and sufficient air comes through the bed of hot coke to burn thoroughly all of the gases. Such a balance now exists between the amount of gases generated and the amount of air supplied that the best possible conditions for maximum economy and smokeless combustion obtain. Finally, the gases are all distilled, and a bed of coke remains, which, as long as it is thick enough with relation to the air supply, will burn under good conditions for economy; but, as soon as it burns down low and the air spaces become large enough to allow an excessive supply of air into the furnace, a new condition of poor economy is reached, the excess of air passing up the chimney, carrying away heat which should have been utilized in the boiler.

Conditions of Perfect Combustion.—Coal can be burned economically without smoke provided that:

1. The gases are distilled from the coal slowly.
2. The gases, when distilled, are brought into intimate contact with a sufficient quantity of very hot air.
3. They are burned in a hot fire-brick chamber.

4. While burning, they are not allowed to come in contact with comparatively cool surfaces, such as the shell or tubes of a boiler; this means that the gases shall have sufficient space and time in which to burn completely before they are allowed to come in contact with the heating surfaces.

In a few words, the necessary conditions for burning coal economically and without smoke are:

1. A sufficiency of air.

2. The air must be brought into contact with the fuel, both solid and gaseous.

3. The mixture of the gases and the air must be maintained for a sufficient time at a temperature of incandescence.

The fundamental condition of perfect combustion of bituminous coals is that every particle of the gas distilled from the coal, including the water gas made by decomposing its moisture, be brought in contact with a sufficient supply of very hot air to burn it, the mixing of the gas and air taking place at a sufficient distance from the heating surfaces of the boiler so that they do not become cooled below the temperature of ignition before the combustion takes place.

Marine boilers are not designed to fulfil the above conditions. They have to be placed in contracted spaces, low down in the ships; they have to be made as light and as small as possible for the power required of them; the fire is always close to the heating surfaces; the combustion-chamber spaces are always contracted; from the nature of their use and the places they have to go, the fire-brick work has to be kept down to the minimum limit, and the conditions generally are against maximum economy with smokeless combustion. With the limitations in boiler design, the best that can be done is to select a good system of firing for that particular boiler and for the kind of coal generally used, properly train the firemen in the system, and see that the system is carried out.

There are four systems of firing, each of which has its claims for recognition, and also its faults. The systems are as follows:

1. **Even-Spread Firing.**—In this system, the fireman spreads the coal evenly, beginning at the back of the grate and working towards the door. The intervals between firing and the amount of coal fired at each time vary with the experience of the engineer in charge and with the kind of coal and amount of draft in use. Some coals burn better with a thick fire, with the coal fired in large quantities at long intervals; others give better results with a moderately thick

fire, using a shorter interval and a smaller charge of coal. The most economical methods of burning various coals under varying drafts can be determined only by experiment, and the economical working of the plant depends entirely on the attention given to these points by the engineer in charge.

As regards efficiency, there is not much difference between a thick and a thin fire, unless it be too thick or too thin. If the fire be too thick, say over 10″ to 12″, with different coals, the air supply will be choked, and incomplete combustion with the formation of carbonic oxide will result; and the carbonic oxide will escape unburned with a great loss in economy. If the fire is too thin, say under 5″ to 6″, with different coals, holes are more liable to be burned in it, giving an excess of air, with a consequent loss of economy and, perhaps, damage to the boiler. The best thickness depends upon the quality and the size of the coal, the draft and the rate of firing.

Objections to the even-spread system are as follows:

(a) When the coal is spread evenly over the whole grate, the fine coal chokes the air passages through the bed of coke on the grate and reduces the air supply at the time when it is most needed to burn the water gas and hydrocarbon gases distilled from the fresh coal.

(b) When the coal is first fired, if spread evenly over the furnace the moisture in the coal is distilled from it, a cooling process which is taking place all over the grate.

(c) The formation of water gas when the steam in (b) is brought in contact with the highly heated carbon on the grate is a cooling process and also takes place all over the grate.

(d) The formation of smoke due to the incomplete combustion spoken of in (a).

2. **The Coking System.**—In this system the fresh coal is piled on the front of the grate, while the rear half is covered with partially burned coke. The gases distilled from the fresh coal then pass over the rear half of the grate, through which an excess of air is entering, the air being highly heated as it passes through the bed of coke. The two gases, one containing the distilled gases, the other the heated air, intermingle in the combustion chamber, or in the combustion space of a water-tube boiler, and are completely burned to carbon dioxide and steam. When practically all of the gases are distilled from the fresh coal on the front half of the grate, it is

pushed back over the rear half and levelled, and, either immediately thereafter or in a short space of time, fresh coal is again placed on the front half of the grate. With coals giving a very fusible ash in large quantities, the coking system cannot be used to advantage, for in pushing the coked coal to the rear half of the grate the coke and ash lying thereon (which may have been kept below the fusing temperature by the air passing through it) becomes mixed with the coked coal; the coked coal burns very rapidly just after being pushed back, generates a very high temperature, melts the ash and causes it to run and choke the air spaces in the grate, thereby decreasing the air supply and causing the coal to burn uneconomically.

The coking system involves a greater amount of care and labor on the part of the fireman than the even-spread system. The extent to which the coking system produces economical smokeless firing depends upon the character of the coal, the skill of the fireman and the size of the combustion-chamber space. The lower the percentage of volatile matter and moisture in the coal, the less smoke will be made with any system of firing.

If the charge of coal is kept small, the firing interval and charge kept uniform and the bed of coal at the back of the furnace kept level and not too thick, the firing will be economical and there will be little smoke.

The larger the combustion-chamber space in which the smoky gas and the hot gas charged with air unite, the longer will be the time afforded for their mixture, and the result will be more complete combustion and decreased smoke.

3. **Alternate Side-Firing System.**—This system seems to have all of the advantages of the coking system without its disadvantages. It consists of spreading fresh coal on one side of the grate over its whole length, then over the other side, alternately, at equal intervals of time. Instead of covering the whole grate with fresh coal at long intervals, only half of the grate is covered at each firing and the firing interval is shortened to one-half the time. After each firing the volatile gases from the fresh coal rise from it, and become mixed with the hot gases and hot air from the other half of the grate, resulting in more complete combustion and less smoke. With this system of firing, economical and smokeless combustion depend in a large measure upon the skill of the fireman, but more especially upon the size of the combustion-chamber space and the opportunity it affords for the thorough admixture of two currents of

gas. Alternate firing is of no use unless there is ample combustion-chamber space in which the two currents of gas are mixed and the smoke is burned before the gases come in contact with the comparatively cool heating surfaces.

4. **Alternate Front- and Back-Firing System.**—This system is the same as that above except that the fresh coal is alternately fired on the front and back halves of the grate, instead of the right and left halves. The action of the gases is the same and the results are practically the same.

Improper firing is probably the most common of all the many causes of poor economy of steam boilers. Often the fact that an improper method of firing is being used can be ascertained by careful observation, but at times it can only be discovered by a series of systematic tests.

No Particular System Adopted in the Navy.—Up to the present time no one of the four systems of firing described above has been adopted in preference to the others. The method of firing water-tube boilers having more than one door to each furnace approaches very nearly the alternate side-firing system. That part of the furnace that can be fired through one door is covered evenly all over with coal at one signal to fire, and that through another door at the next signal, thereby keeping one part of the furnace covered with green coal while other parts are covered with coke.

Economical firing has taken rapid strides in the past few years. The even-spread system is the only one in practical use in the navy in fire-tube boilers having only one door to a furnace, though there is reason to believe that more economy may result from the alternate back and front or alternate side firing; for it is probable that with these systems there will be better combustion of the volatile gases and smaller losses, on account of lowering the temperature below the ignition point when the fresh coal is thrown on.

Bad Firing.—Much can be learned by observing the mistakes of others and avoiding them. Some of the mistakes made by ignorant or negligent firemen are:

1. Putting too large a quantity of coal on the fire at a time, covering the fire so thick that the air supply is choked, resulting necessarily in incomplete combustion.

2. Firing at irregular intervals, sometimes having the fire too thick, and again allowing it to burn so low that holes are burned in it, or so low that a large excess of air is passed through it,

diluting the gases of combustion, and thereby sending too much heat up the smoke-pipe and reducing the furnace temperature.

3. Neglecting to cover the whole of the grate surface properly, allowing holes to burn in the fire at places and having the fire too thick in others. This can result in having an excess of carbonic oxide and an excess of oxygen in the smoke-pipe gases at the same time, if the excess of air passed through the thin fire at one place and the excess of carbonic oxide formed where the fire is too thick are cooled below the temperature of ignition before they are mixed.

4. Not keeping the fires properly cleaned, thereby choking the air supply and causing imperfect combustion.

Errors in firing, requiring a series of boiler tests or an analysis of the smoke-pipe gases for their detection, are often committed by the most careful and intelligent firemen without any suspicion that they are in the wrong. These are: (1) Carrying the bed of fire too thick or too thin on the grate for the size of the coal and the force of the draft; (2) unskilful regulation of the draft.

Good Firing.—The best method of firing is the one that will insure that the smoke-pipe gases contain no carbonic oxide (CO) and no hydrogen or hydrocarbon gases, and at the same time contain not more than 6% of free oxygen.

The presence of combustible gases, even in very small quantities, in the smoke-pipe gases is a sign of imperfect combustion and the consequent loss of economy. The presence of from 4% to 6% of free oxygen in the smoke-pipe is usually a necessary accompaniment of complete combustion. A greater quantity means an unnecessarily large supply of air, and consequently unnecessary loss due to heating the excess of air. The percentage of carbon dioxide in the smoke-pipe gas is not as good a criterion of the furnace conditions as would be obtained from a quantitative analysis of smoke-pipe gases showing the percentage of CO_2, CO and O. A wrong idea prevails that when the percentage of CO_2 is as high as possible the boiler economy is a maximum. This is true only when the analysis of the gases shows *no* CO, and only a reasonable amount of free oxygen, not over 6%. The presence of *any* CO indicates a heat loss, which rises quickly with the rise in CO percentage. Table II B, Appendix, shows the large value of this loss. In some boilers, notably those on shore with large combustion chambers, the percentage of CO_2 will run high, say up to 13%, and yet no CO will be present in the gases. In other boilers, where the combustion chambers are small, as soon as the CO_2

percentage runs above a certain limit CO begins to show up in the flue-gas analysis, bringing with it the large heat loss. This limit with the marine type of boiler is about 10% of CO_2.

In order, therefore, to get the best results from a boiler some form of gas-analysis instrument must be at hand by which the percentage of CO_2, CO and O can be determined. Then a good rule for economical firing would be:

Keep the percentage of CO_2 as high as possible, consistent with the absence of CO and with the presence of O in small amounts—never over 6%. These conditions can be fulfilled only from experiments made by the engineer in charge of each individual plant.

Where the thickness of the fire and the force of the draft are under the control of the fireman or water tender, as they are on board naval vessels, good results may be obtained with either thin, medium thick or thick fires, if the force of the draft is regulated in proportion to the thickness of the fires. The proper thickness of the fire and the proper force of the draft to be used with the coal on hand have to be determined by experiment, or by observation by the engineer in charge, to determine that force of draft and that thickness of the fire used that will give the best results.

The best regulation of the force of the draft and the thickness of the fire is that which makes the hottest fire. If an integrating pyrometer giving the average temperature of the fire over the whole of the grate could be made, it would be the ideal indicator of the furnace conditions. Deficient air supply, causing imperfect combustion, and excessive air supply, causing too great a dilution of the gases of combustion, both tend to cool the furnace. The hottest fire that can be made is one in which the air is enough in excess to insure perfect combustion and no more. The hottest fire is also obtained when the smoke-pipe gases show by analysis from 4% to 6% of free oxygen. The analysis of the smoke-pipe gases, therefore, gives an excellent indication of the furnace conditions.

Intelligent Supervision of Firing.—Competition has become so keen, both in the navy and on the outside, that it is imperative that those in charge of an engineering plant get the maximum efficiency from the fuel.

Pointers on Firing.—1. Keep a good, bright fire. The color of the flame should be a light yellow. When dark shadows are thrown into the ash pan, it is an indication that there is clinker formed on the grate, directly above; this clinker prevents the air from getting

through, and results in incomplete combustion. Use the slice bar on such clinkers, removing them at once, and do not make a dirty fire wait on the clock.

2. Avoid excess of air. The greatest loss in furnace practice is due to excess of air. The waste chargeable to this cause will probably, in ordinary cases, be ten times that due to incomplete combustion. Excess air may enter in the following ways:

(a) Through open furnace door. Place coal in the best position for throwing it in the furnace and work rapidly when the door is open. The CO_2 charts show material reduction of CO_2 when the doors are open. Any means of reducing the period of open door will pay. There is a great difference in furnace temperatures between the conditions of open and closed furnace doors; the resulting contractions and expansions are bad for the boiler.

(b) Through badly fitting furnace doors and furnace fronts. The fit of the doors and fronts should be made good and kept in that condition.

(c) Through the grate. Keep all the grate covered and all the fire clear of holes, bare spots, hills and hollows. A bare spot on the grate is the worst enemy of the coal pile.

3. There is no absolute rule as to the height of fire to carry. Fires for natural draft should be carried roughly from 8″ to 10″, and for forced draft a little thicker. A thin bed of fuel will admit more air to the furnace chamber than a thick one. It is a matter of pressure (draft), and resistance (thickness of fuel); there is a relationship between the two which must be studied with each fuel and each furnace to operate furnaces with the greatest economy. This relationship can best be studied by analyzing the gases of combustion.

4. Find the draft and thickness of fire which will give best average percentage of CO_2. Too high a percentage of CO_2 entails a likelihood of too much CO; in addition to the CO, there is probably some unburned hydrocarbon gases which are lost.

5. When fires require slicing, slice them, and at no other times; the same applies to raking and cleaning.

6. Use a time-firing device to fix the stoking interval, as it leads to uniformity. The device should not be used to regulate anything but the stoking interval, as the times for slicing, raking and otherwise working the fires must be dictated by human judgment. When the bottom of the fire is in bad condition, it requires

slicing or cleaning; when the top is in bad condition, it requires raking; trouble on one side of a fire cannot be cured by treating the other.

Under natural-draft conditions, Burnot found that when burning about 11 pounds of coal per square foot of grate surface per hour, the efficiency increased as the firing interval and weight of charge were decreased. He found evaporative efficiencies as follows (ordinary coal):

With charge equal to 1 shovelful	9.64
With charge equal to 2 shovelfuls	9.38
With charge equal to 3 shovelfuls	9.18
With charge equal to 4 shovelfuls	8.91

In this connection it has been found that if the boiler dampers are partly closed when the furnace door is open, the efficiency is increased.

7. Boiler dampers are the throttle valves of the draft, and should receive as much attention as the steam throttles, or any other controlling device in the plant. When the damper is closed, the vacuum in the furnace and passes of the boilers is decreased. The lever for regulating the dampers should be long, and the more holes in the arc for regulating the position of the dampers the better. For controlling the steam supply, use the dampers and ash-pit doors—never open the furnace doors for this purpose, as it causes too much expansion and contraction. Never throw on green coal for checking the supply of steam; it does check the steam supply, but it is coal wasted.

8. Leaks of air into the uptakes cause great waste of heat units. One of the most marked improvements in recent years in boiler economy has come from having tight boiler casings. The excess of air coming through these leaks is simply so much air to be heated, and the process cools the heating surfaces. Analysis of combustion gases near the furnaces and further on near the uptake will show whether there are uptake leaks. A lighted candle carried around the joints will also show where there are leaks. The leaks can be stopped by some effective kind of cement or plaster. Some one man aboard ship should be charged with the regular duty of seeing that the casings are kept tight.

No air should be allowed to flow through the passages of any boiler except at the furnace.

The above pointers, used intelligently in connection with a fair

knowledge of what chemical reactions take place in the furnace, should give economical firing.

Rates of Combustion.—When considering the question of firing, one of the most important points is the rate of combustion, or number of pounds of coal burned per square foot of grate per hour. The low limit to rate of combustion is that rate below which it is impossible to go without allowing holes in the fire.

When dampers are used with judgment, coal can be burned efficiently at a low rate. The standard rate of combustion in the Pacific fleet is 12 pounds per square foot of grate per hour. According to Rankine, Deakin, Kennedy, Hutton, Coxe and others, the amount of air required for the complete combustion of coal *decreases* with an increase in the rate of combustion. This increases furnace temperature, increases efficiency of the heating surfaces, decreases temperature of gas in the smoke-pipe, and decreases the smoke-pipe losses.

The decrease in the temperature of the escaping gases will not follow, if the increase in combustion rate is obtained by decreasing the number of boilers in use. It does appear to follow, however, if for a given boiler the same total amount of fuel is burned, the rate of combustion being increased by reducing the grate area. Tests show that by blocking off some of the grate area, and increasing the rate of combustion (by burning the same amount of coal as would have been burned on the whole grate), the evaporation per pound of coal has been increased as high as 15%. This resulted in the increase of CO_2, and gave a boiler efficiency of as high as 75% or 80%. When the rate of combustion is high, the fires cannot be kept thin without loss of efficiency. For a given draft, the heavier the fire the less the rate of combustion; but, for a fixed rate of combustion, the efficiency increases with the thickness of the fire up to a certain maximum allowable thickness.

With a rate of combustion of 27 pounds, Richardson and Fletcher found efficiencies to vary with thickness of fire as follows:

Thickness of fire.	Evaporation per pound of coal.
9″	10.77
12″	11.23
14″	11.54

Hutton states that, with forced draft, fires should be at least 10″ thick to reduce excess-air losses. The stronger the draft, with con-

sequent greater rate of combustion, the thicker the fire should be. Where increase in capacity is desired, the fires should be carried thinner; with a given draft, the thinner the fire (without holes), the greater the rate of combustion.

Experiments by reducing the grate area and correspondingly increasing rate of combustion gave the following results:

Rate of combustion, 14 lbs. Lbs. of water evaporated per lb. fuel, 10.10
Rate of combustion, 23 lbs. Lbs. of water evaporated per lb. fuel, 10.91

There are times when the grate can be shortened temporarily; this reduces the reserve power, but according to experimental results there is a gain in economy.

TABLE SHOWING RATES OF COMBUSTION AND EVAPORATIVE POWER.

Name of ship.	Speed knots.	Rate of combustion.	Air pressure in fire-rooms.	Evaporation on trial. Water per pound of coal.	Water per pound of coal from and at 212° F. on evap. test.	Air pressure for col. 6.	Type of boilers.
1	2	3	4	5	6	7	8
Delaware........	21.56 19.217 12.24	37.487 20.71 14.5	1.86 .45 (†)	9.26 10.02 9.60	*10.47 11.91 11.23	1.86 .45 (†)	B. & W. fitted with superheaters.
Utah	21.04 19.22 12.02	30.47 18.48 15.525	1.15 .78 .20	10.08 11.13 9.95	11.5 11.45 11.32	.90 .0 .0	B. & W.
Birmingham	24.326 22.668 12.225	42.96 29.47 19.95	2.53 1.98 .25	8.60 9.0 9.7	9.55 10.10 10.88	2.40 1.25 .60	Fore River express type; return flame.
Chester..........	26.522 22.782 12.20	55.08 25.95 17.63	2.74 .70 (†)	8.75 9.35 9.55	8.10 9.50 9.70	2.50 .85 (†)	Normand.
Preston..........	29.177 24.14 16.135	64.84 32.85 22.166	2.84 .77 .40	7.75 8.15 8.70	*8.48 8.80 9.23	2.84 .77 .40	Thornycroft.
Reid............	31.82 24.72 16.40	57.84 28.54 19.64	5.19 1.46 .78	9.95 10.10 10.90	*10.70 ? 12.90	5.19 1.46 .78	Normand return flame.

* Evaporation from and at 212° F. for ships that are starred in this column is worked from the data given on the trial trips, using the temperatures of the feed water and pressures of steam at the boiler as given in the Journal of the Society of Naval Engineers. No account is taken of the quality of the steam, as the data in regard to it are not given, and probably were not recorded. 970 B. T. U. is used as latent heat of steam at 212° F. in these calculations.

Utah's values from test of B. and W. boiler for *Arkansas* and *Wyoming*. *Birmingham* and *Chester* values from evaporative tests run during competitive trials.

† Natural draft.

Cleaning Fires.—In six or eight hours after fires have been started in a boiler, depending on the character of the coal and the rate of combustion, the grate bars begin to choke with ashes and cinders. This can be seen by a casual observation of the under side of the grate bars. When the fire is clean and burning properly, the under side of the grate will show bright all over it; but when the fires are dirty and the grate bars are choked, there will be dark patches under the choked portions, which are easily seen as they throw shadows in the ash pan. When it is seen that the fires are becoming dirty, the cleaning of the fires is begun; and during the remainder of the run the fires are cleaned regularly every 12 hours, or more often if necessary. The fires to be cleaned each watch are marked, and the division is made so that each watch will clean one-third of the fires in each boiler. In a boiler with two furnaces, with three doors to each, one fire from each furnace should be cleaned each watch. When a fireman sees that there are clinkers in any of his fires, he should remove them as soon as they are discovered, whether it is his fire to clean or not.

When the ash-hoisting engine was the only means of clearing the fire-rooms of ashes, the practice in cleaning fires was for the watch going off to burn down the fires that its relief was to clean. The new watch would then clean its fires as quickly as it could be done, while maintaining steam at the proper pressure. The chief water tender gave directions as to how many fires were to be cleaned simultaneously. The practice of allowing the watch going off to burn down the fires for the relief is bad, especially so when steaming in fleet. The fires, when burned down, are not in the proper condition to make steam, and practically one-third of the fires are in that condition. With water-tube boilers, an increased demand for steam demands its immediate production, and if the ship drops out of position when the fires are burned down or at any time before they are all cleaned and are burning up properly, it is impossible to regain the position until the fires are all in proper condition. For a watch to burn down the fires its relief is to clean sometimes leaves the relief in such a position that it does not get its fires up to proper condition during the whole of the watch. Prior to the installation of ash ejectors, fires were cleaned early in every watch, for the job of clearing the fire-rooms of ashes was a long one, and therefore much effort was made to get all fires cleaned and ashes ready to hoist as soon as possible after the watch came on.

The better practice, especially with water-tube boilers steaming in fleet, is to let each fireman burn down the fires he is to clean, under the supervision of the chief water tender; the fires will then be cleaned in rotation, steam pressures will not be allowed to fall, and, with ash ejectors as now installed, the ashes can be sent overboard at any time during the watch after all the fires in that fire-room are cleaned.

The limit to the number that can be cleaned simultaneously is governed by the steam pressure, and by whether all other fires are burning freely. If the steam pressure is low, or the boilers are not steaming freely, only a few fires can be cleaned at one time.

In cleaning the fire, the good coal and coke is shoved to one side of the furnace and the clinkers are raked out of the furnace and wet down with the hose provided for the purpose. If clinkers stick to the grate bars, the slice bar is used as a pry to loosen them. In case of clinkers sticking to the grate bars near the furnace front, the lazy bar placed across the furnace front can be used as a fulcrum, making a lever by the slice bar. Clinker near the rear of the furnace is pried off by raising the fire-room end of the slice bar. All tools must be at hand and everything must be ready before starting to clean a fire, so that the time taken to do the job will be as short as possible. When one side of the furnace is cleaned, the good coal and coke is shoved to the clean side and the other side is cleaned. After cleaning a fire, spread the burning coal and coke and cover the bare places with fresh coal, and fire lightly until the coal is burning freely over the whole furnace area; then build the fire up gradually to normal thickness.

Hoisting Ashes.—The ashes in the ash pit should be hauled frequently, and the ash and clinker from cleaning fires should be removed from in front of the furnace to some place near the ash hoist or ash ejector, care being taken that they are not piled against any bulkhead plates. Boards, put against the bulkheads temporarily, make a good protection. When the ashes have been removed, the guard plates on the boiler front, the front of ash pits, and the fire-room floor in front of the furnace should be swept clean. This will prevent the accumulation of wet ashes and leave a clean place for the next round of coal.

The older types of naval vessels have steam ash-hoist engines. On this type the fire-rooms are usually cleared of ashes at five bells of the watch. The ashes are hoisted to a deck above the water-line,

trollied by the deck force over to the side of the ship and dumped through ash chutes. Most of the newest ships are supplied with ash ejectors, and this means of clearing the fire-rooms of ashes will be understood from the description of ash ejectors.

When hoisting ashes under forced draft in a closed fire-room, some care must be taken to keep the proper door of the tube or ventilator, through which the bucket is hoisted or lowered, closed to prevent the escape of air. By using the bell and speaking tube fitted for communication between the fire-room and the deck, this can be done easily, and also much unnecessary noise and delay be avoided.

CHAPTER XII.

DRAFT, NATURAL AND FORCED.

It has been shown in the discussion of combustion that it requires a certain definite number of pounds or cubic feet of air to furnish the requisite amount of oxygen for the complete combustion of each pound of fuel; also that the complete combustion of a pound of fuel generates a certain definite number of heat units, depending upon the nature of the fuel. The capacity of a boiler, then, for generating steam at a definite pressure, the grate area and heating surface being fixed, depends upon the rate of combustion (the number of pounds of fuel burned in its furnaces per hour). The rate of combustion depends upon the *draft,* which is the supply of air to the fires.

Smoke-Pipe Draft, Natural Draft.

The draft produced by the smoke-pipe alone is due to the fact that the gases inside the chimney are hotter and consequently lighter than the outside air. The pressure of the air at the top of the smoke-pipe, due to the atmosphere above that level, is the same on the gases on the inside of the smoke-pipe as on the air outside. The pressure at the bottom of the smoke-pipe, on the inside, is the sum of the pressure of the air at the top of the smoke-pipe and the pressure due to the column of hot air in the smoke-pipe. The pressure at the same bottom level on the outside of the smoke-pipe will be that at the top plus the pressure due to a column of cold air as high as the smoke-pipe. The difference of these pressures inside and outside is considered to be the *natural draft,* in all theories of smoke-pipe draft.

Calculation of Natural Draft.—To illustrate the calculation of the draft or difference of pressure due to any assumed conditions, we will take an example. The smoke-pipe is 80 feet high above the grate; the temperature of the gases in it is 450° F.; and the temperature of the air outside is 80° F. The draft is calculated as follows:

The weight of a cubic foot of air at 32° F., and at the average atmospheric pressure of 14.7 pounds per square inch, is about .0807 pound. The weight of air at a given pressure is inversely propor-

tional to its absolute temperature (459.5° + degrees F.). Therefore, the weight of a cubic foot of hot gas and of a cubic foot of cold air in the example taken are:

$$\text{Hot gas} = .0807 \times \frac{459.5+32}{459.5+450} = .0436 \text{ pound.}$$

$$\text{Cold air} = .0807 \times \frac{459.5+32}{459.5+80} = .0735 \text{ pound.}$$

A column of hot gases 80 feet high and 1 foot square will weigh $.0436 \times 80 = 3.488$ pounds and will give that pressure per square foot on a diaphragm at the level of the grate. The cold air outside will give a pressure of $.0735 \times 80 = 5.88$ pounds per square foot.

The difference of pressure, or the *draft,* will be $5.88 - 3.488 = 2.392$ pounds per square foot, or $2.392 \div 144 = .0166$ pound per square inch.

The hot gases of combustion at a given pressure and temperature have a slightly greater specific gravity than air at the same temperature and pressure; but the difference is very slight and may be neglected.

A variation in the pressure of the atmosphere and of its temperature will affect these pressures, and the draft in the assumed smoke-pipe will vary with them.

To find the draft in inches of water instead of pounds, we consider that 1 cubic foot of water weighs 62.4 pounds; consequently a column of water a foot square, which produces a pressure of 2.392 pounds per square foot, will be $2.392 \div 62.4 = .0383$ foot high, or $.0383 \times 12 = .4596''$ high. The draft in the example given above, .0166 pound per square inch, equals .4596" of water, practically ½"

Limitations of Natural Draft.—This amount of pressure will drive only a certain definite quantity of air into the furnace in a unit of time, and therefore the number of pounds of coal per square foot of grate per hour that can be burned in the furnace is correspondingly limited.

We should therefore, with natural draft, be restricted in any given ship to a given amount of steam produced by the boilers, the variation in this amount being small and depending chiefly on the weather conditions, and should consequently be limited to a certain speed, as was the case in the earlier warships.

If the height of the smoke-pipe were made greater, the draft would be increased, and consequently the amount of coal burned, or the rate of combustion, would be greater. This rate of combus-

tion is expressed in *pounds of coal burned per square foot of grate surface per hour.* But the smoke-pipe cannot be lengthened indefinitely, the usual height on large ships now being about 100 feet above the grate surface. With this height, the coal consumption may be as much as 20 pounds per square foot of grate per hour under natural draft.

Increasing the number of boilers would increase the amount of steam produced, but the weight and space of the boiler installation would also increase. But as the weight of, and the space occupied by, the machinery (which includes engines, boilers and auxiliaries) on board modern warships are very important factors, the number of boilers is limited.

Forced Draft.

We must, therefore, increase the steam-producing power of the given boilers by artificial means, and this is done by increasing the rate of combustion by the use of some system of *forced draft,* which term includes all degrees of increase in the rate of combustion when produced by artificial means. Some form of forced draft is all the more necessary on most modern high-powered ships, as, owing to the fitting of a protective deck and the very restricted openings left in it for air to reach the fires, natural draft is almost an impossibility.

Not only is the steaming power of the boiler increased by the use of forced draft, but, when moderately applied, the efficiency of the combustion is increased.

The systems now in use are: (1) *Steam jet;* (2) *closed ash pit;* (3) *induced draft;* (4) *closed fire-room.*

Steam Jet.—This system is the easiest to fit; but on account of its waste of steam, it is used only on steam launches or small boats, which can easily renew the fresh water lost. The steam is drawn from the boiler and blown through small holes in a pipe into the base of the smoke-pipe, or above or below the grate, thus inducing a current of air to follow from the outside. To overcome the waste of steam, compressed air has been tried, but its use is very limited.

Closed Ash Pit.—Air is forced by centrifugal fan blowers, rotating at high speed, through ducts into the ash pit and furnace, the openings of which are tightly closed. It is an efficient and generally a simple system, and permits open fire-rooms. With

fire-tube boilers, as on the *Monadnock* and *Montgomery,* the air ducts are led under the fire-room floor to the front of each ash pit, where they end in a casing which covers the ash-pit opening and

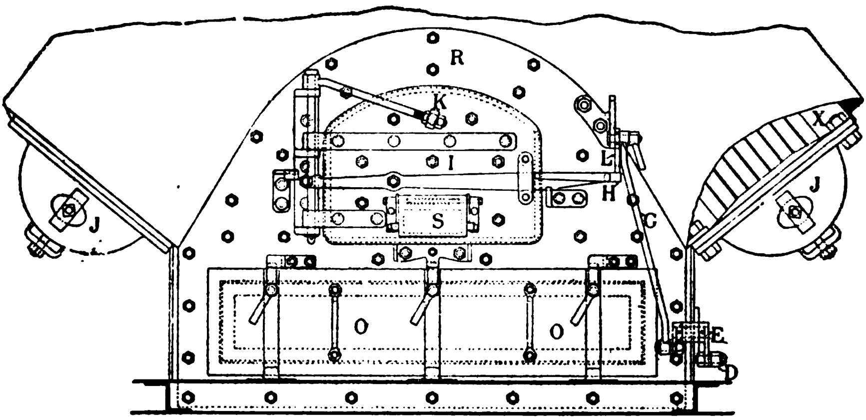


FIG. 96.

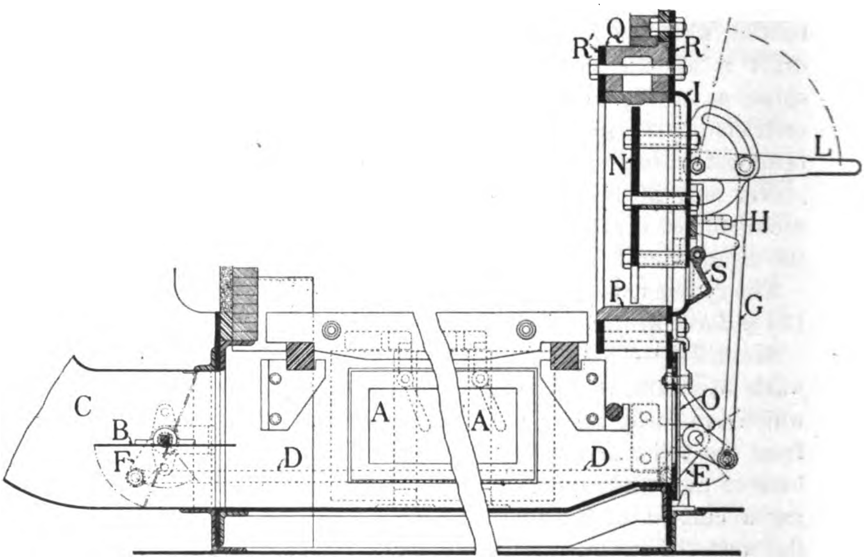


FIG. 97.

which is provided with a door in front and a damper on a level with the bottom of the ash pit.

This system is not now installed in armed vessels of the United States Navy.

The general principles of this system will be understood from Figs. 96 and 97, which show the general arrangement. Fig. 96 is a front elevation of the lower part of the boiler, and Fig. 97 is a vertical longitudinal section through the center of the furnace and ash pit. The ash pit *AA* and furnace have been shortened for convenience. The furnace door is shown at *I;* the ash-pit door, at *O;* and the duct through which the air enters, at *C.*

The door *O* is made air-tight by an asbestos gasket secured around its edges, this gasket being slightly compressed when the door is lowered into the sockets below and the three wedge bolts above are secured by their handles. The furnace door *I* fits closely around its edge to the furnace front, and is held in that position by the handle *H.* The small slicing door *S,* being of heavy cast iron, allows no air to escape, except a little under very strong draft.

The damper *B* at the back of the ash pit is shown open, the dotted lines showing its position when closed. Connected to the spindle on which *B* moves, and on the outside of the boiler casing, is the crank *F,* which is moved by the handle *L,* to the right of the furnace door, by means of the rods *D* and *G* and the cranks at *E.* *L* has a curved projection on its under side, which, in the position shown, is held firmly against the top of the furnace door handle *H.* *L* has motion upward in the slotted arc, and can be held firmly in any position by the handled lock nut to the right. *H* cannot be raised nor the furnace door *I* be opened, until the lock nut on *L* is eased and *L* is raised, and then *B* must close and the air be shut off.

Howden's System.—This is a closed ash-pit system, but combined with means for heating the air before it reaches the fires. The air heater consists of a nest of thin tubes fitted in the uptake, the products of combustion passing through the tubes, and the air for combustion passing around them. Special provision is made for the regulation of the air supply above and below the grate.

When the system is fitted to fire-tube boilers, the grate is made shorter than usual, and it is level or slightly raised at the back. In addition to these changes, both generally conducive to economy, the boiler tubes are fitted with *retarders.* These consist of strips of thin metal, twisted into a spiral, which are pushed loosely into each tube. By retarding the egress of the gases, and thus keeping them in contact with the tube surface for a longer time, more heat is abstracted, and increased efficiency follows under forced combustion.

All of the ducts and casings must be kept air-tight, or the hot air will be forced into the fire-room.

As this system utilizes all of the means which have been shown to be necessary to economy and perfect combustion, it follows that when it is properly worked, the boiler efficiency will be increased.

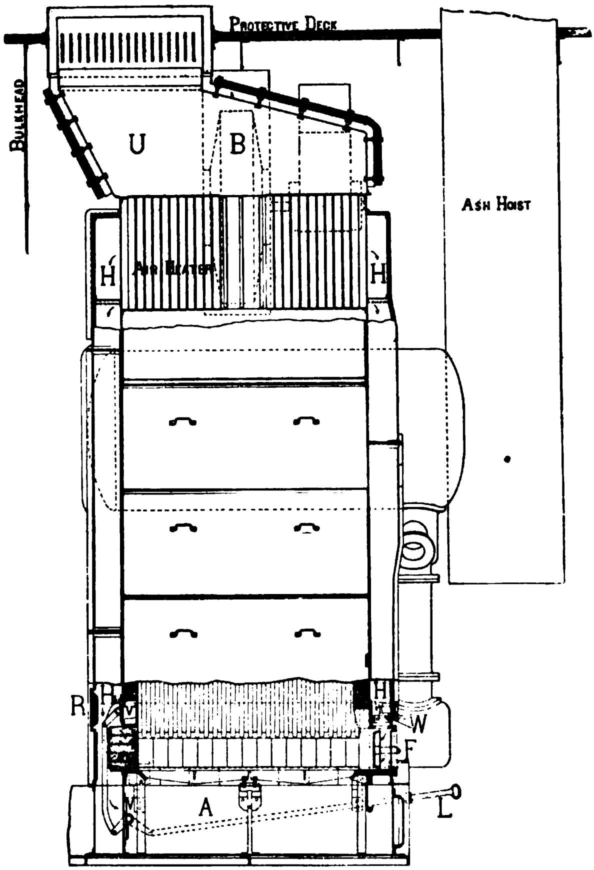


FIG. 98.

Fig. 98 shows a side elevation, partly in section, of the arrangement of this system on a Thornycroft boiler. The boiler casing is shown complete in the middle part of the boiler, and is removed at the top and bottom.

B is the blower situated at the top and on one side of the boiler. The air heater is composed of 416 tubes, $2\frac{1}{2}''$ in diameter, and has a heating surface of 793 square feet, or a little over ten times the grate surface. Air ducts *H, H* are built on the front and back of the boiler to guide the air to the furnace fronts and to openings in the back wall and back of ash pit, as shown by the arrows. The products of combustion pass upwards from the furnace, around the boiler tubes, and through the tubes of the air heater into the uptake *U*.

Above each furnace door *F* is an opening covered by a flat valve *W*, which can be moved by a handle from the outside. The supply of air to the front part of the fire can thus be regulated. In the back wall, some distance above the grate, there is a perforated plate extending almost the whole width of the grate. By means of the damper *V'*, the supply of hot air from *H* to the top of the fire can be regulated. The main supply of air enters the ash pit *A* through the large damper *V*. Both dampers are worked together by the rod *L* from the front of the boiler. A handhole *R* is provided in the back of the casing for the easy examination of damper *V'*.

Induced Draft.—This name applies properly only to the system by which an upward current of air through the boiler is induced by means of a blower at the base of the smoke-pipe, or in the uptake of each boiler. The blower required is much larger than that for the closed fire-room system, and is very liable to dangerous overheating. When a separate blower is fitted in each uptake, the draft can be regulated for each boiler separately as required. British naval experience showed that, while on other grounds there is little choice between this induced, or Martin's, and the closed fire-room system, the great advantages of working with an open fire-room remain with the induced draft.

The most prominent ships fitted with this system are the British battleships *Magnificent* and *Illustrious*. The system is not used in the U. S. Navy.

Ellis and Evans' System.—This is an induced-draft system with closed ash pits, combined with means for heating the air for combustion. In the latest type of this system, the air is drawn past the outside of the heating tubes, as in Howden's. As the pressure of the air is less in the casings and ducts, these need not be so carefully fitted. Arrangement is made for air distribution above and below the grate, similar to Howden's, but better.

Heating the air for combustion results in economy if the heat which is used for this purpose would otherwise be wasted. Thus. if the heat which is radiated from the boiler casing is used to heat the air for combustion, the result will be increased economy, because of the resulting higher furnace temperatures, other conditions remaining constant.

Closed Fire-Room System.—This system is now more generally in use on warships than any of the others. In this system, the air is forced by blowers directly into the fire-room, all hatches and doors being closed air-tight, and must find its way out through the furnaces.

It has these disadvantages: (1) The arrangement of air locks, ventilators, bunkers and special air-tight bulkheads is costly, and the weight is considerable. (2) The men are imprisoned in the fire-rooms by numerous doors and hatches, and must work in an atmosphere surcharged with coal dust.

Communication between the fire-rooms, or between the compartments under pressure and those not under pressure, is effected by means of air locks. These are small spaces, each closed by two doors. After passing through the first door, it is closed before the second one is opened, thus reducing the loss of pressure to an inappreciable quantity.

In order to reduce the fire-room space, which must be kept under pressure, special air-tight bulkheads are often fitted. With water-tube boilers, the ash pit and other air doors in the casing are so arranged that they will close automatically in case of a sudden outrush of steam, such as would follow the bursting of a tube. One form of this door is shown in Fig. 23, the axis on which it turns being above the middle of the door. It is held open in any position by means of the counter-weight at the top of the door, and by the notched lever. It is closed automatically by the excess pressure on the larger area. In another form, the door is inside the casing and hangs from supports which are well above the opening. The air pressure swings the door open, and any steam pressure would close it.

Air-Pressure Gages.—The usual method of measuring the air pressure or the draft, is by the difference in level of the water contained in the two legs of a glass U-tube, one end of which is open to the atmosphere and the other to the fire-room or air duct under pressure.

Fig. 99 shows the ordinary air-pressure gage, without its case. The top of leg *A* is led to the atmosphere when this gage is used with the closed fire-room system, *B* being open to the fire-room. When the closed ash-pit system is used, *A* is connected to the air duct near the ash pit, *B* being then open to the atmosphere in the fire-room. Scale *C* is graduated in fractions of an inch to represent the difference of level or pressure, the zero mark being in the middle of its length or height. When there is no pressure, the water level should be at zero. If it is not, water should be added or taken out in order to facilitate the reading of the scale. It will be readily understood that a pressure exerted on the water level in *B*, which will force it down 1″, will raise the level in *A* 1″, and that the pressure is equal to that of a column of water 2″ high. This is, therefore, the air pressure in the fire-room or air duct.

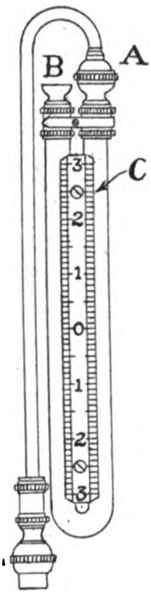


FIG. 99.

The scale may be more conveniently arranged for reading by adopting a sliding scale, graduated from zero up. When a difference in the two legs is shown, the zero of the scale is put opposite the lower level, and the reading of the air pressure is taken from the higher level. No attention need then be paid to the quantity of water in the U-tube.

As the air pressure is frequently given in ounces (per square inch), it will be well to show the relation between inches and ounces.

A cubic foot of fresh water at 62° F. weighs 62.355 pounds; or, a column of water 1728″ high and having an area of 1 square inch will weigh the same, or, in other words, will exert a pressure of 62.355 pounds per square inch. Therefore, 1 pound per square inch would be exerted by a column $1728 \div 62.355 = 27.712''$ high, or 1 ounce per square inch would be exerted by a column of water 1.732″ high. Taking the reciprocal of this, 1″ of water column is equal to a pressure of .577 ounce per square inch.

Rate of Combustion.—So long as the amount of coal burned per square foot of grate surface under natural draft was sufficient for the requirements of the time, no especial effort was made to use forced draft, although all systems had been tried on naval vessels long ago. When, however, the desire for increased speeds

became paramount, following the introduction of the torpedo boat, forced draft was again taken up, about 25 years ago. The first object was to obtain higher powers with a given boiler; and later, to increase the economy of combustion.

Under natural draft, which is usually considered to be equivalent to an air pressure of about ½″, the rate of combustion varies from 15 to 25 pounds, the latter being reached under most favorable conditions. Following Mr. Thornycroft's experiments with a closed fire-room, in which from 80 to 120 pounds and even more of coal were burned per square foot of grate, requiring air pressures of from 4″ to 8″, the rate of combustion on larger ships was much increased for a time. But leaky tubes and a general failure of boilers led to a steady reduction of air pressure, so that now the limit allowed for our large ships is 2″. Torpedo boats and destroyers are not, of course, so limited, 5″ and 6″ being usual, although the limit for the later destroyers is 4½″. At this latter pressure, the rate of the combustion varies from 55 to 65 pounds with the best coal. With air pressures ranging from ¾″ to 1″, the rate varies from 30 to 40 pounds.

Significance of Draft in Boiler Practice.—The word *draft* relates to the flow of gases through the boiler furnace, gas passages and stack. It is rather loosely applied in practice, and hence may not be accurately defined. As shown previously, the flow of gases between two points is caused by a difference of pressure existing at these points. In the case of natural draft this difference in pressure is due to the difference in weight of a column of hot gases and an equal column of cold air. With forced draft the difference in pressure is due to the increase in pressure in the fire-rooms (or at the ash pit) over the atmospheric pressure at the stack. In either case, the resultant flow of gases is due to a *pressure difference.*

The difference in pressure between the air at the ash pit and the gases in the uptake is called the *total pressure drop through the boiler and furnace.* This pressure drop is measured in inches of water.

The difference in pressure between the air in the fire-room (or ash pits) and the gases over the fuel bed is called the *pressure drop through the fuel bed.*

The difference in pressure between gases over the furnace and the gases in the uptake is called the *pressure drop through the boiler.*

Method of Measuring Pressure Drop.—Pressure drop is generally

measured by means of U-tubes, one leg of each tube extending into the gas passage and the other end being open to the atmosphere. The *difference* in reading of the U-tubes will then indicate the pressure drop between the points at which the tubes are installed. If there is a considerable *vertical* distance between the two U-tubes, the pressure drop must be corrected for the difference in atmospheric pressure between the two points. For example, if one tube is 30 feet above the other, the *apparent pressure drop* (difference in U-tube readings) must be corrected for the vertical height by adding about .48″ of water to the pressure drop—or the equivalent weight of a column of air 30 feet high.

Effect of Pressure Drop.—If the total pressure drop remains constant, the pressure drop through any part of the gas path will increase with the resistance, while the weight of gases flowing through that part in a definite time will be decreased. Thus, if the fuel bed is doubled in thickness, or density, the pressure drop through the fuel bed will be doubled but the amount of air flowing through will not be increased.

Practical Value of Pressure Determinations.—If the pressure drops through the fuel bed and through the boiler are measured, fairly accurate determinations may be made of the proper thickness for fires and the times for cleaning fires. Thus, if the pressure drop through the fuel bed is excessive, there will be too little air passing through the fuel and too little draft through the boiler, resulting in poor economy. The remedy is a thinner fire, or cleaning the fire if needful. Any decrease of air through the fuel bed due to clinker or the formation of a crust on the surface of the bed is indicated by the increased pressure drop through the fuel bed.

Forced Draft for Liquid Fuel.—With the systems of burning liquid fuel now in use, forced draft is a necessity, especially so with mechanical atomization, and with these systems the construction of the furnace and the method of admitting the air are of equal and paramount importance. The oil spray is generally thrown off from the tip of the burner in the form of a cone. The air for combustion should be given a whirling motion around the oil spray, and there should be sufficient air to surround each particle of the fuel completely and cause its complete combustion. The direction of the rotation is immaterial, but the velocity and method of controlling and producing the whirling air current are of vital importance in their effect on the combustion, and also on the shape and character of the resulting flame.

The air current should have a velocity enough greater than that of the oil spray to enable the air to overtake the particles of oil and completely surround them. The quantity of air per pound of fuel

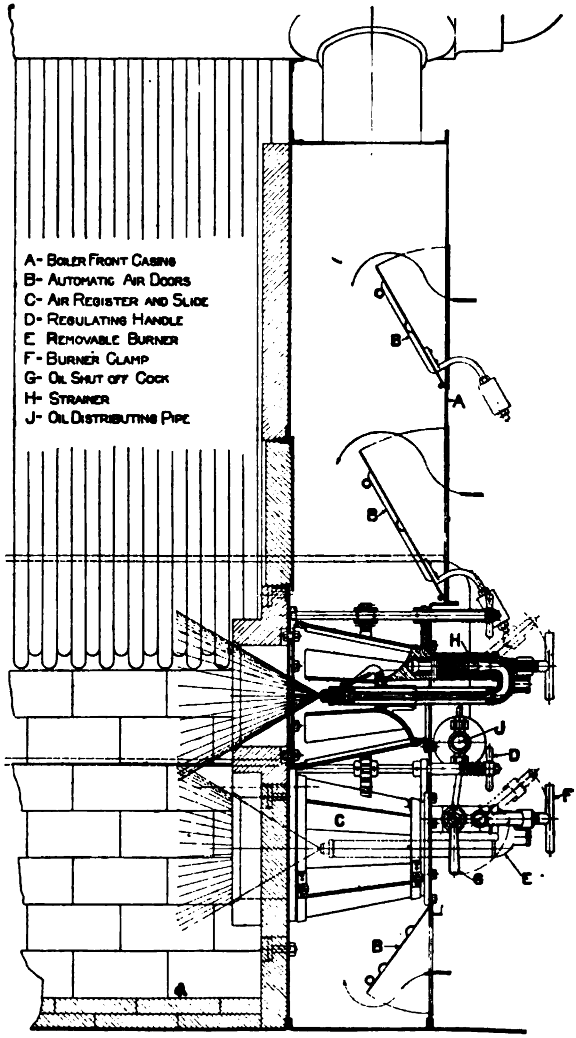


FIG. 100.—Koerting Patent Oil-Firing System in Boilers of Torpedo-Boat Destroyers.

need then be only slightly more than sufficient to cause the complete combustion of the fuel. It is the aim of the designer to obtain the required results with the least air pressure possible.

Fig. 100 shows the fitting of the boiler front of a torpedo-boat destroyer boiler. The fittings here described represent in a general way the manner of fitting all types of air registers and fuel oil burners in the boiler fronts of those U. S. naval vessels whose boilers are fired with oil only. Limited space necessitates modifications of burners, shape of spray, air supply thereto, etc., in boilers designed to burn coal with oil as an auxiliary fuel.

The outer casing *A* has automatic air doors *B*, admitting air under pressure into the space between the inner and outer casing. The air is admitted to the burner through the air register and slide *C*, which has slots cut in its periphery, covered by an outer casing with similar slots in it; this outer casing is moved around the inner casing by the regulating handle *D*, thereby regulating the amount of air entering the furnace. The amount of air depends upon the amount of opening of the slots in *C* and upon the pressure of air in the fire-room. The regulating handle *D* works a rod carrying a pinion, which engages a rack on the outer casing of *C*.

The air pressure on destroyers using liquid fuel is carried as high as 6″ of water.

The maximum efficiency with desired steam pressure is readily maintained by altering the draft pressure with the oil supply. Any great increase or decrease of capacity should be taken care of by lighting or extinguishing additional burners, each of which has its individual air register and slide, so that it can be turned on full when the burner is lighted, or shut off entirely when it is extinguished, the air pressure in the fire-room being increased or decreased accordingly by controlling the speed of the blowers.

The closed fire-room system is used entirely on our liquid-fuel-burning destroyers.

The proper continuous control of the oil flame is very important, not only on the score of economy and efficiency in making steam, but also as a tactical feature in the making, or discontinuance of smoke screens.

CHAPTER XIII.

CORROSION AND WATER TREATMENT.

CORROSION.

Corrosion is essentially the dissolving of metals and is generally accompanied by the subsequent oxidation of such metal in solution. It may take the form of a rust coating over the entire surface, called *general corrosion,* or it may be restricted to small areas, in which case it is termed *pitting.*

Causes.—Corrosion is due principally to the tendency of metals to dissolve in water, aqueous solutions and films of moisture. The metal so dissolved is readily oxidized in contact with free oxygen in the solution or above the surface of the solution. Three theories have been advanced to account for this action. All theories agree that the presence of moisture and oxygen are necessary conditions. The three theories are:

(1) The Acid Theory of Corrosion.

According to this theory, corrosion can occur only in the presence of carbonic acid or of some other acid in solution. It is supposed that such acids start the corrosive action and act as carriers of metal to oxygen, maintaining the process indefinitely. It has been shown, however, by numerous experiments, that corrosion may take place when iron is immersed in pure distilled water from which all carbonic acid or other acids have been expelled.

(2) The Hydrogen Peroxide Theory.

This theory is based on the assumption that the formation of hydrogen peroxide is a necessary step in the formation of rust.

Experiments, however, show that while hydrogen peroxide does induce corrosion, it is not essentially a factor in all corrosive actions.

(3) The Electrolytic Theory.

The electrolytic theory is based on the fact that all metals tend to go into solution. This tendency to go into solution is electrolytic in character and is due to a difference of potential existing between

the metal and the solution or between two metals immersed in the same solution and metallically connected. A difference of potential between two points on the surface of the same metal is sufficient to cause the metal to dissolve, provided the solution is of lower potential than one of the points.

For example, if two metals are metallically connected in the presence of an electrolyte, one of them dissolves while the other is protected, the whole process being accompanied by an electric current flowing from one metal through the solution to the other metal. Where there is a single metal only in the solution, the different points on the surface which are at different potentials act in reality like different metals.

Metal so dissolved is readily oxidized by any free oxygen in the solution and is precipitated as rust, thus allowing more of the metal to dissolve.

The electrolytic theory is generally accepted, but a detailed discussion of it is beyond the scope of this work. It must be remembered, however, that a thorough understanding of the principles involved is essential to their practical application, and much damage may be done through ignorance and unintelligent application of the theory.

Experimental Results.

Corrosion in Distilled Water.—Experiments made with iron strips immersed in chemically pure distilled water show that corrosion occurs at varying rates, the amount of rust formed being dependent upon (1) the purity of the metal, (2) the amount of oxygen present in the water, and (3) the temperature of the water. In general, the amount of corrosion will depend directly upon the amount of oxygen having access to the water and present in the water. Impurities in the iron, points of high potential on the surface due to the working of the metal, and the amount of carbon present in the metal, all influence the rapidity of corrosion.

Experiments have been undertaken with the view of excluding the air from the water by means of a protective film of oil on the surface. This method has proved ineffective, however, since the oil absorbed oxygen from the air and further transmitted it to the water.

If all air is excluded from the water no corrosion occurs, but as soon as air is allowed access to the immersed metal, corrosion occurs rapidly.

When *pure distilled water* is made sufficiently alkaline, no corrosion occurs, but there is always the danger here that if the solution is not kept sufficiently alkaline, pitting will occur. It has been held that *chemically pure iron* immersed in pure distilled water will not corrode, but since chemically pure iron is not commercially obtainable, and must also be free from internal strains and improper hammering, it need not be considered.

The Corrosive Effect of a Couple Immersed in Solution.—When two different metals are metallically connected and immersed in water or an aqueous solution, a difference of potential will be set up between them similar to that in a battery, and if this potential is sufficiently great (depending on the character of the metals), one of them will dissolve while the other will be protected. Thus, in a copper-iron couple the iron will corrode while the copper will be protected.

If zinc is connected to iron and immersed in an aqueous solution, the zinc will corrode and protect the iron until the zinc becomes coated with zinc oxide, after which the action ceases.

It has been maintained that since *zinc oxide* is electro-negative to iron, the current will be reversed and the iron will corrode faster than if no zinc oxide were present, but this contention has not been sustained by experiment.

The temperature of such couples immersed in solution has an important bearing on the amount of corrosion which will occur, since the electrolytic potentials of metals and solutions, and the amount of oxygen in solution, vary also with the temperature. In general, the difference of potential between metal and solution will increase with increase of temperature. The temperature at which maximum corrosion takes place is about 160° to 180° F.

The Effect of Acids on Corrosion.—If an acid is present in the solution, the corrosive effect is increased, and the rate at which corrosion progresses under such circumstances depends directly upon acid strength of the solution.

It is worthy of note, however, that a piece of iron dipped in fuming nitric acid will resist corrosion for reasons which have not as yet been satisfactorily explained. This protection is only temporary, however, and has no practical application.

Corrosion of Alloys.—The electrolytic potential of an alloy is different from that of any of its constituents, generally lying between them.

Bronze and brass alloys generally have a low potential and hence are not readily corroded by salt water. This makes naval bronze a good material for use on under-water fittings of ships, such as outboard delivery valves, etc.

The Effect of Sodium Chloride.—Sodium chloride (NaCl), which is present in distilled sea water, has a marked effect on corrosion. By increasing the conductivity of the water the corrosion is accelerated. Where steel or iron is protected by being in metallic contact with zinc, the result of NaCl in solution is to increase the protective effect, and extend it over a greater area.

If boiler water is made *sufficiently* alkaline by the addition of soda, lime or other compounds, corrosion will be prevented. The necessary alkaline strength in distilled water free from NaCl has been found to be about 3% of a normal solution. *When sodium chloride or other salts are present, a higher alkalinity will be necessary, depending on the amount of salt present in solution.*

The use of alkalies for this purpose is dangerous in one particular. Just before the point at which corrosion is prevented is reached, the rusting will be confined to a few spots and will take the form of *pitting*. If the alkalinity is never allowed to exceed 0.5%, however, pitting will not take place, and this alkalinity will insure that the water does not become acid.

Keeping the alkalinity at 0.5% will not prevent corrosion entirely if any oxygen is present in the water; but *pitting* will be prevented, and such corrosion as does occur will be general and not so dangerous to the safety of the boiler.

WATER TREATMENT.

Reasons for Treating Boiler Water.—There are three reasons for treating boiler water, viz.: (a) To render it as nearly non-corrosive as possible, (b) to prevent the formation of scale, (c) to prevent the rise of surface tension and consequent priming caused by the impurities in the water and by the application of the remedies for (a) and (b). *Surface tension* is the molecular action of a liquid which resists any force tending to break through the free surface. This causes priming in boilers by its resistance to the flow of the steam bubbles through the surface, and therefore the boiling action is more violent and particles of water are carried over with the steam.

Boiler Compounds.

Boiler compounds are mixtures of electrolytes, which, when dissolved in feed water, are claimed to fulfill the requirements given under (a), (b) and (c) in the preceding paragraph. There are many boiler compounds on the market of various degrees of merit; some of them are very good, but *all are injurious if used without the proper degree of intelligence.*

Experiments show that good homogeneous steel immersed in distilled water corrodes almost equally over its wetted surface. As the concentration (*i. e.,* the percentage of normal alkaline solution) is increased by the addition of an electrolyte such as boiler compound, the *rate* of corrosion is at first slightly *decreased,* and after a certain concentration is reached, the rate of corrosion is *increased.* An *electrolyte* is a substance which increases the electrical conductivity of water when the substance is dissolved in the water. At a certain definite concentration the rate of corrosion reaches a maximum, and then falls off rapidly as the concentration increases, reaching a definite point at which corrosion ceases, *provided no salt is present in the water.* If any salt is present in the water, a higher concentration will be necessary before corrosion is prevented, *the concentration necessary to prevent corrosion increasing with the amount of salt in solution.*

It is evident, from this, that it is better to use no treatment than to use any chemical or compound without knowing, by test pieces, whether the water is actually corroding the boiler metals. The method of using such test pieces is described later in this chapter. There is also the danger that the saturation concentration will be reached and the chemical will be deposited as scale. This, however, is not probable with the Standard Navy Boiler Compound.

The following are some of the qualities required in any compound used in the treatment of boiler water:

(1) It must contain one or more metallic elements that have a higher electrolytic potential than the material of the boiler, preventing the metal from going into solution.

(2) It must contain some strong alkali to make the water alkaline at low concentrations.

(3) It must be incapable of being broken down into other compounds giving acid reactions within the range of temperature to which the boiler water is subjected.

(4) It must be soluble at these temperatures.

(5) It should not be conducive to priming by increasing surface tension.

(6) It should contain some chemical compound which will combine with any scale-forming elements and keep them in suspension as sludges.

The chemicals generally used are alkaline earth metals, due to their high solubility, high solution tension and low cost. *Solution tension* is a measure of the tendency of metals to dissolve when placed in aqueous solutions.

Composition of Boiler Compounds.—Sodium carbonate (Na_2CO_3) is found to be one of the best agents in the treatment of water to prevent corrosion. Fig. 102 shows the results of tests at the Engi-

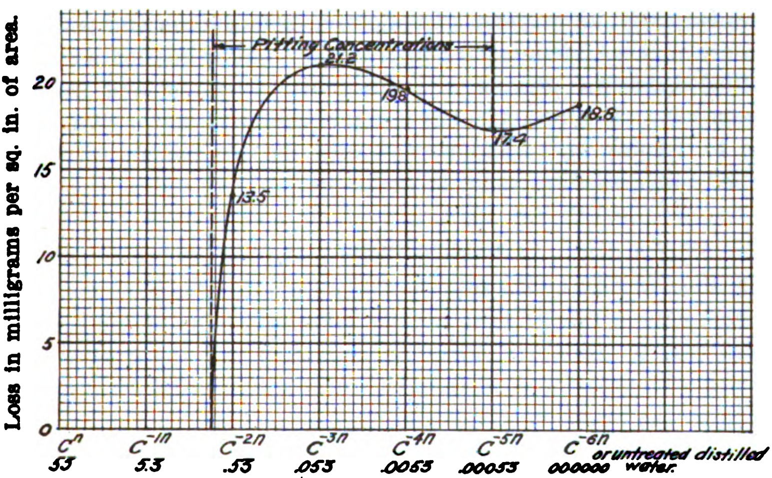


FIG. 102.

neering Experiment Station, Annapolis, Md., by putting pieces of steel in water treated with various amounts of Na_2CO_3. The treatment periods were of 30 days each. The curve is the average of 12 periods. The solutions were made in distilled water. C^n is normal solution (defined on page 289). In addition to sodium carbonate, lime is sometimes used as an electrolyte, but this has the disadvantage of being conducive to priming and is liable to be precipitated. Caustic soda and di-sodium phosphate are also used in some boiler compounds.

A boiler compound which, under tests, seems to be very satisfactory was evolved during 1910, at the Engineering Experiment Station, Annapolis, Md. It consists of (1) 95% calcined sodium carbonate (Na_2CO_3); (2) 4% di-sodium phosphate (Na_2HPO_4, $12H_2O$); and (3) 1% of cutch or catechu. The first ingredient makes the solution non-corrosive, the second prevents priming and the third prevents formation of scale. The cutch is an organic compound containing 40% to 45% of tannic acid; this has the property of preventing formation of scale, as it converts the foreign salts of the water from crystalline to colloidal state, and holds them in suspension within the range of boiler temperature. Starches and dextrines also have this property. The function of the di-sodium phosphate is to prevent the surface tension that causes foaming and priming. In addition, both sodium and potassium are very soluble and very high in the solution tension series. Distilled water was treated with the above compound and made non-corrosive; the solution had 3% normal alkaline strength. Evaporated to dryness, baked and treated with the original amount of distilled water, the compound all redissolved.

Impure Water.

We will now take up the subject of impure water, the precipitates formed by the action of heat and the chemical action of the compounds used to render the water non-corrosive, and the treatment required to change these precipitates into their colloidal form and hold them in suspension in the solution.

Water appears in nature in two forms: (1) That of the ordinary state, that of the water of crystallization in compounds precipitated from ordinary water solutions.

The purest water found in nature is rain water after it has rained for a time; the first rain that falls absorbs the impurities in the air and is, therefore, impure.

As soon as rain water comes in contact with the earth and starts on its course to the sea, it begins to dissolve various substances according to the nature of the soil with which it comes in contact. Streams that flow over sandstone beds contain exceptionally pure waters, as sandstone is very insoluble. Those that flow over limestone beds dissolve some of the stone and the water becomes "hard." The many varieties of natural mineral waters are due to substances from the earth being dissolved in the water.

All natural water is, therefore, more or less impure, and the impurities vary with the nature of the soil in the territory through which it has passed. In order to get pure water it must be distilled and kept free from air.

When pure distilled water is used in boilers, the treatment required is (1) an electrolyte to raise the potential of the solution and prevent the metal from dissolving, and (2) one to prevent the high surface tension that causes priming.

Natural water from limestone localities contains calcium acid carbonate in solution; when the water is heated this is converted to calcium carbonate ($CaCO_3$) and precipitated. At 300° F. it is practically all precipitated as a sludge, if the water contains no other impurities. If it contains calcium sulphate or magnesium carbonate or sulphate, it forms a hard scale. With the magnesium and calcium sulphates, as they are precipitated, calcium carbonate sludge acts as a binder, cementing them into hard scale. Water from localities containing magnesium compounds dissolves magnesium in the form of the acid carbonate and the sulphate. Magnesium carbonate precipitates as a magnesium hydroxide ($Mg(OH)_2$), which is soluble only to about ½ grain per gallon. Magnesium sulphate ($MgSO_4$) is quite soluble at boiler temperatures, but in the presence of $CaCO_3$ it forms magnesium carbonate ($MgCO_3$) and calcium sulphate ($CaSO_4$), both of which are only slightly soluble. In presence of sodium chloride ($NaCl$) it forms very soluble sodium sulphate (Na_2SO_4) and magnesium chloride ($MgCl_2$).

Calcium sulphate is found in natural waters, and under ordinary conditions of temperature it is soluble to about 100 grains per United States gallon. Its solubility decreases with a rise in temperature, and at about 300° F. it is practically all precipitated.

Streams that flow through localities containing salt ($NaCl$) contain it in solution in comparatively large quantities.

Natural fresh waters have in them, as the principal impurities, carbonates, sulphates and chlorides in quantity in the order named. The principal carbonate is the acid carbonate of calcium $Ca(HCO_3)_2$, the principal sulphate is that of magnesium $MgSO_4$, and the principal chloride is that of sodium $NaCl$. The metals calcium, magnesium and sodium are cations in electrolytic dissociation.

Sea Water.—Sea water contains the impurities contained in the waters emptying into it and those absorbed from the soil of its bottom.

The average composition of the water of the oceans is about 3.5% salts and 96.5% water.

COMPOUNDS FOUND IN THE SEA WATER.

Salt—sodium chloride	$NaCl$
Magnesium chloride	$MgCl_2$
Magnesium sulphate	$MgSO_4$
Magnesium bromide	$MgBr_2$
Potassium sulphate	K_2SO_4
Calcium sulphate	$CaSO_4$
Calcium carbonate	$CaCO_3$

COMPOSITION OF SALTS FOUND IN OCEAN WATER (ABOUT).

	Per Cent.
$NaCl$	77.76
$MgCl_2$	10.88
$MgSO_4$	4.74
$CaSO_4$	3.60
K_2SO_4	2.46
$CaCO_3$	.34
$MgBr_2$	.22

The maximum percentage of salts found in sea water is 3.737%, the average percentage 3.5%. The mean density of sea water is 1.027.

The percentage of salts in sea water may range from 1 to 4, but the percentage of each salt has been found to remain practically constant.

The principal impurities in sea water are chlorides, sulphates and carbonates in the order named. It may be seen that the order of the salts as to quantity in sea and natural fresh waters is just reversed. Sea water dissolves only 83% as much oxygen as does fresh or distilled water.

It is now seen that the scale-forming ingredients in water, both natural fresh water and sea water, are the calcium sulphates, calcium carbonates and magnesium hydroxides. When sea water is treated with sodium carbonate, enough of it must be added to the water to precipitate all of the salts with which it will react, and then enough more to bring the normal alkaline strength of the solution up to a certain definite percentage. This percentage has been found to be about 2.5 for ordinary good steel boiler plate. The reactions that take place when treating sea water with sodium carbonate are as follows:

Mineral salts in sea water.	Chemical with which sea water is treated.	Compound formed that is insoluble within the range of temperatures of boiler water.	Compounds formed that are incompletely soluble within the range of temperatures of boiler water until near the point of saturation.
$NaCl$	Na_2CO_3	......	$NaCl$ and Na_2CO_3
$MgCl_2$	Do.	$MgCO_3$	$NaCl$
$MgSo_4$	Do.	Do.	Na_2SO_4
$CaSO_4$	Do.	$CaCO_3$	Do.
K_2SO_4	Do.	......	K_2CO_3 Na_2SO_4
$MgBr_2$	Do.	$MgCO_3$	$NaBr$
$CaCO_3$	Do.	$CaCO_3$	Na_2CO_3

These insoluble salts are all precipitated at a temperature of 300° F. as calcium carbonates and magnesium hydroxide, the carbonate of the magnesium compound being transformed into carbonic acid gas and driven from the water as CO_2 at temperatures above the boiling point. These, then, are the compounds that must be converted into their colloidal states and prevented from forming hard scale on the heating surfaces. This is done by the cutch in a boiler compound.

Notes on Solutions in General.

Valence is that property of an element by virtue of which its atom can hold a definite number of other atoms in chemical combination.

(1) If a chemical compound is an acid, its valence equals the number of replaceable hydrogen units it contains.

(2) If it is a salt, its valence equals the number of replaceable hydrogen units in the acid from which the compound was formed.

(3) If it is a base, its valence equals the number of hydroxyl (OH) units in it from which the hydrogen of water has been displaced.

EXAMPLES OF VALENCY.

Valency.	Univalent.	Bivalent.	Trivalent.
Acid	HCl	H_2SO_4	H_3PO_4
Salts	$NaCl$	$CuSO_4$	Na_2HPO_4, $12H_2O$
Base	$NaOH$	$Ca(OH)_2$	$Cr(OH)_3$

A normal solution in water of any chemical is made by taking a weight of the pure substance in grams $=\frac{\text{molecular weight}}{\text{valency}}$, dissolving it in distilled water and adding distilled water until the

volume comes up to one liter. If water of crystallization is present in the chemical, it is included in the molecular weight in accordance with its chemical formula. A normal solution of HCl contains $\frac{1+35.4}{1}$ grams of HCl per liter of solution; one of H_2SO_4 contains $\frac{2+32+64}{2}=49$ grams per liter; one of Na_2HPO_4, $12H_2O$ contains $\frac{2\times23+1+31+4\times16+12(2+16)}{3}=$ 119.3 grams per liter of solution.

A normal solution has normal strength when it has the correct amount of chemical and the chemical and water ingredients are pure. The normal solution of any acid will just neutralize the hydroxyl in an equal volume of any normal basic solution, and *vice versa.* The normal solution of pure dry calcined sodium carbonate (Na_2CO_3) contains $\frac{46+12+48}{2}=53$ grams per liter of solution. If the water is not pure (suppose, for instance, it contains some of the salts found in sea water), the sodium carbonate will react with some of these, decreasing the amount of sodium carbonate, as such, in the solution. If the compounds formed by the carbonate and the foreign matter are less dissociated in the solution than the pure carbonate, the activity of the solution as a preventer of corrosion is decreased.

The percentage of normal alkaline strength of any solution of a base is measured by neutralizing the alkali in a measured volume of it with an acid the percentage of normal strength of which is known; the amount of acid used is carefully measured. Suppose, for instance, it takes 15 cc. of one-tenth normal acid to neutralize the base in 50 cc. of alkaline solution; then the normal alkaline strength is $\frac{15}{50}\times\frac{1}{10}=\frac{15}{500}=\frac{30}{1000}$, or 3%. The equation may be written as follows: $\frac{\text{volume of acid used}}{\text{volume of sample neutralized}}\times$ percentage of normal strength of acid used = the percentage of normal alkaline strength of the solution from which the sample was taken.

Practical Methods of Water Treatment.

Three methods have been used in the United States Navy to prevent corrosion in boilers, viz.: (1) The use of zinc plates, specially rolled and metallically connected to the boiler plate, and immersed in the water; (2) the use of sodium carbonate (Na_2CO_3), caustic soda and other boiler compounds to keep the water sufficiently alkaline to prevent all corrosion, or at least to insure that only general corrosion may occur; and (3) the exclusion of air from boiler feed water by the use of oxygen extractors.

The use of zincs for boiler protection has been abandoned, as their effectiveness was limited.

Where boiler compounds or alkalies are used, a good procedure is to keep a piece of boiler plate in a sealed jar full of the boiler feed water and to note the effect on the test piece from time to time. If, then, the alkalinity is sufficient to cause pitting to occur, the test piece will indicate the fact. It must be borne in mind, however, that the percentage of alkalinity necessary to prevent corrosion depends upon the quantity of NaCl in the water; and since this quantity is subject to wide variations in a short time, there is danger that the alkali may become insufficient to prevent corrosion due to an increase of NaCl in the feed and that dangerous pitting may result. Therefore, *the only safe method is to keep the percentage of alkalinity at 0.5%.*

The exclusion of air from the feed water is being satisfactorily accomplished by means of oxygen extractors placed on the branch feed lines to the boilers in front of the feed stop and check valves. If care is used to restrict the access of air to boiler feed corrosion will be reduced to a minimum.

Protective coatings of paint on the ship's hull inside and out are effective in inhibiting corrosion, but the subject of protective paints is beyond the scope of this work.

Salt water pipes are successfully protected by lead linings, while under-water fittings connected to the steel hull have zincs attached for the protection of steel fittings. Special care should be taken to prevent the painting of such zincs when the ship is docked, since a coat of paint protects the zinc at the expense of the hull and under-water fittings.

The use of electric currents to prevent corrosion has been successfully used, but has not been adopted by the naval service. This

device consists of an insulated electrode immersed in the boiler water supplied with a direct current from an independent source. The negative lead is taken from the boiler proper. In this manner a current is made to flow from the electrode through the water to the boiler and back to the source, causing the electrode to waste away and protect the boiler proper. The current must be kept on continuously and must be supplied by an independent generator, otherwise any heavy grounds in the ship's circuit will stop the current through the boiler. If the current is shut off, the corroded particles become electro-negative to steel and form a battery of which the shell is the anode, causing rapid deterioration of the boiler.

Chemical Testing Outfit.

This apparatus is for the purpose of ascertaining the quality of feed water as regards acidity, neutrality or alkalinity and for finding its chlorine content.

Fig. 105 shows an outfit containing the necessary equipment for making the above determinations, numbered as follows:

1. Case containing the outfit.

2. Spring clamp on the door of the case for holding the burette when making a test.

3. White porcelain bowl for holding the sample of water under test.

4. Burette secured in place by clamp 2 and ready for use.

5. Pipette for dropping indicators into sample.

6. Glass stirring rod.

7 and 8. Spare burettes. All burettes are graduated to 100 cc. in tenths of cubic centimeters; they have a white back with a vertical blue line on it by means of which the position of the bottom of the meniscus of the liquid can be accurately judged.

9. Case carrying two B. and W. measuring bottles. Each bottle has a zero mark near its bottom. The space between each of the graduations holds 5 cc., but the graduations are marked 0, 50, 100, etc.

10. Case holding a bottle of red and a bottle of blue litmus papers.

11. Glass measuring cylinder graduated in cubic centimeters to 100. (Not shown.)

12. Case holding small beaker for pouring chemicals into burette.

13. Liter bottle of nitric acid of strength one-half normal.

14. 500 cc. bottle of anhydrous sodium carbonate or normal strength.

15. Liter bottle of silver nitrate solution containing 4.101 grams of pure silver nitrate in one liter of solution in distilled water.

16. Bottle of methyl orange solution, consisting of $\frac{1}{10}$ gram of methyl orange powder dissolved in 1000 cc. of distilled water.

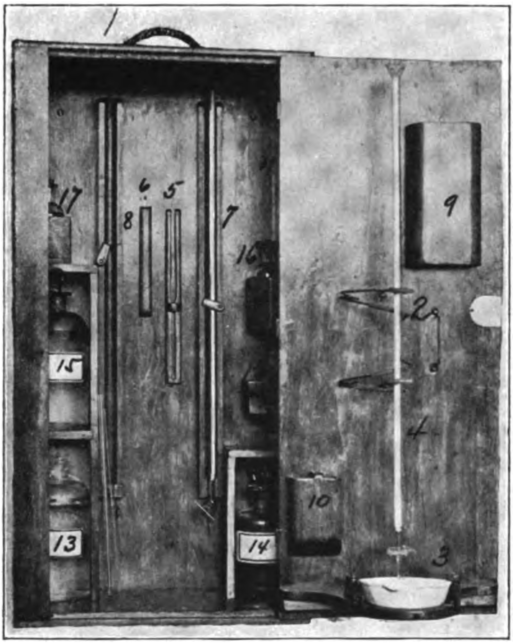


FIG. 105.—Chemical Testing Outfit.

17. Bottle of potassium chromate indicator of tenth normal strength.

The principle involved in the tests is the simple chemical volumetric determination of the acid or alkaline strength of the sample of water under test, or the number of grains of chlorine per gallon contained therein.

The outfit furnished ships consists of the case and the instruments and containers described above, but does not include the chemicals. The latter must be obtained upon requisition from the general store-

keeper at a navy yard, in sufficient quantities to last for a considerable length of time.

Indicators.—The determinations are made by the use of indicators, which give a change of color to the solution when its nature changes.

Methyl orange solution, when dropped in an acid solution, causes it to turn a faint pink. It changes the color of an alkaline solution to a pale yellow.

Blue litmus is turned red in an acid solution and is unaffected in a neutral or an alkaline solution.

Red litmus is turned blue in an alkaline solution and is unaffected in an acid or neutral solution.

The color reactions of litmus are delayed in water containing carbonic acid gas, and are therefore inaccurate in case of such water. To obtain accurate color reactions in solutions containing carbonic acid gas when using litmus, the solution must be boiling during the test.

When running silver nitrate into a solution containing chlorine, to which the *chromate indicator* has been added, a white precipitate will be thrown down until all of the chlorine has been precipitated as silver chloride. This is due to the fact that the silver in the nitrate combines with the chlorine in the water, thus:

$AgNO_3 + NaCl = AgCl$ (white precipitate) $+ NaNO_3$ (colorless in solution).

$2AgNO_3 + MgCl_2 = 2AgCl + Mg(NO_3)_2$.

When all of the chlorine in the solution has been removed, the silver of the nitrate then combines with the chromate of the indicator, forming a silver chromate solution, which is red, thus:

$K_2CrO_4 + 2AgNO_3 = Ag_2CrO_4$ (red solution) $+ 2KNO_3$ (colorless in solution).

Volumetric Determinations.—In volumetric determinations of alkalinity and acidity the percentage of normal strength of the alkaline or acid solution is determined.

A *normal solution* of any volume of an acid will exactly neutralize an equal volume of a normal solution of any alkali or base, and *vice versa.*

A liter of a normal solution of any chemical contains the weight in grams of the pure chemical obtained by dividing the molecular weight of the chemical formula by its valency.

In any compound whose valency is unity, the normal solution contains the molecular weight of the compound in grams in a liter of the solution.

A liter of a normal solution of HCl (hydrochloric acid) contains $1+35.46=36.46$ grams of pure HCl.

In any compound whose valency is 2 or 3, the normal solution contains one-half or one-third, respectively, of its molecular weight in grams in a liter of the solution.

A liter of a normal solution of H_2SO_4 (sulphuric acid) contains $\frac{2+32+64}{2}=\frac{98}{2}=49$ grams of H_2SO_4.

A liter of a normal solution of H_3PO_4 (orthophosphoric acid) contains $\frac{3+31+64}{3}=\frac{98}{3}=32.66$ grams of H_3PO_4.

Method of Using Testing Outfit.

Alkalinity Test.—Draw a sample of water from the boiler into a glass or porcelain receptacle *which has just previously been washed out with water from the same boiler.*

Fill the burette 4 with acid from bottle 13, using the beaker. Open pet-cock at bottom of burette and draw a few drops of acid through it into the beaker. Repeat this if necessary until all air bubbles have been expelled from lower end of burette and it is filled to tip with acid when cock is closed.

Measure exactly 50 cc. of the sample of boiler water into the glass measuring cylinder, and pour into dish 3, which has just previously been washed out with other water from the same sample, or with distilled water, and wipe dry.

Drop 2 drops of the methyl orange solution from bottle 16 into the sample in dish 3. If the sample is in the least alkaline, or neutral, it will turn a pale yellow when stirred with the glass rod 6.

Read the graduation at the top of the acid in the burette; then from pet-cock at the bottom drop acid into the sample in dish 3, stirring continuously with the glass rod 6 until sample turns a faint pink. Close the pet-cock and read the graduation on the burette at the top of the acid. The difference between the two readings indicates the number of cc. of acid required to neutralize the alkali in the sample.

Each cc. of $\frac{1}{2}$ normal acid used in neutralizing the alkali in a 50 cc. sample indicates 1% of normal alkaline strength.

NOTE.—These instructions require acid to be added until the sample turns a faint pink. This indicates that the alkali has been a little more than neutralized and the sample has become slightly acid. The error, however, will be negligible for the purpose of testing boiler water if the test is carefully made and the pet-cock is closed at the instant that the faintest pink color is attained in the well-stirred sample. For this reason the acid should be added drop by drop and the test should be conducted in a good light.

Chlorine Test.—The sample in dish 3 is now slightly acid. Before testing for chlorine, the sample must be made neutral or slightly alkaline.

Using pipette 5, drop sodium carbonate solution from bottle 14 into the sample until it just turns yellow, indicating that it is neutral or slightly alkaline. One drop should be sufficient.

Replace burette 4 with burette 7, and fill 7 with silver nitrate solution from bottle 15, taking precautions as before to see that it is filled to the tip. Using pipette 5, drop 4 drops of chromate indicator from bottle 17 into sample in dish 3. Read the graduation at the top of the nitrate in the burette; then from pet-cock drop nitrate into the sample in dish 3, stirring continuously with the glass rod 6, until the sample turns a reddish-yellow color throughout. Close the pet-cock and read the graduation on the burette at the top of the nitrate. The difference between the two readings indicates the number of cc. of the nitrate required to precipitate all of the chlorine in the sample.

With this strength of silver nitrate solution, each cc. used in the 50 cc. sample indicates 1 grain of chlorine in each gallon of boiler water.

The stop-cock should be closed as soon as the change in color from yellow to reddish-yellow in the well-stirred sample occurs. If the nitrate is added until the sample is a deep red, erroneous results will be derived. For this reason the nitrate should be added drop by drop after the first sign of reaction occurs, and the test should be made in a good light.

If a light be held under dish 3 while the nitrate is being added, the color reaction will be better defined.

General Instructions.—The percentage of normal alkaline strength, X, of a solution may be expressed thus:

$$X = \frac{A}{S} \times P,$$

where A is the number of cc. of the acid required exactly to neutralize the alkali in the sample of the solution, S is the number of cc. of the sample, and P is the percentage of normal strength of the acid used.

For example, if it is found that exactly 2.2 cc. of a half-normal acid are required to neutralize the alkali in a 50 cc. sample of a solution, then the percentage of alkaline strength of the solution is

$$\frac{2.2}{50} \times \frac{1}{2} = \frac{2.2}{100} = .022,$$

or the solution is 2.2% of normal alkaline strength.

From the above equation it may be seen that any variation from the prescribed size of sample tested, or any variation from the prescribed strength of acid used, will directly affect the accuracy of the determination of the alkaline strength. Every care must be exercised in compounding the reagents and in making the titrations.

To provide reagents of standard known strength, there is kept in store at all naval stations, and obtainable on requisition, a supply of the chemicals properly mixed for use solely with this outfit.

To compound an acid solution of half-normal strength, exactly 32 cc. of standard acid (between 69½ and 70% pure acid by weight) should be mixed with 968 cc. of distilled water. Bottle 13 is supposed to be of 1000 cc. capacity, but commercial bottles vary in size. If the 1000 cc. level is once accurately determined by use of the burette, and marked with a file scratch, the solution can be easily compounded whenever necessary by running 32 cc. of the acid from a burette into the bottle and adding water up to this 1000 cc. mark.

If for any reason the standard acid referred to above is not available, a solution may be prepared by using any acid not containing chlorine (though nitric acid is to be preferred), as follows:

Make up a solution by mixing with distilled water enough of the acid, according to what its strength is known or supposed to be, to make approximately a half-normal solution, and then proceed to determine the exact strength of the solution, thus:

Measure exactly 50 cc. of the acid solution in cylinder 11 and pour into dish 3. Add 2 drops of the indicator from bottle 16 and stir with the glass rod. The sample will turn pink. Fill burette 8 to the tip with normal sodium carbonate solution from bottle 14, and read the height of the solution in the burette. Run sodium carbonate solution into the sample, stirring continuously, and close the pet-cock at the instant that the sample changes color from

pink to yellow, indicating that the acid has been neutralized. Read the height of the solution in the burette and determine how many cc. of the sodium carbonate solution have been used.

Remembering that a given quantity of an alkaline solution of a given strength will exactly neutralize the same quantity of an acid solution of the same strength, that the sodium carbonate solution is of normal strength, and that the sample of acid solution contains 50 cc., it is apparent that if it required, say, 20 cc. of the sodium carbonate solution to neutralize the acid, then the acid strength of the sample is $\frac{20}{50}$, or $\frac{2}{5}$ of normal acid strength.

Suppose that, in testing a sample of boiler water in the manner heretofore described, it is found that 3 cc. of this $\frac{2}{5}$ normal acid is required to neutralize the alkali in the 50 cc. sample; then, employing the equation $X=\frac{A}{S}\times P$, the alkaline strength of the sample is $\frac{3}{50}\times\frac{2}{5}=.024$; in other words, the boiler water is 2.4% of normal alkaline strength.

If the water is very muddy in appearance, it will be found advisable to allow the samples to stand in their original containers, before making the test, until the sediment in the water has settled.

The chlorine test depends upon the fact that, when any volume of solution containing 4.101 grams of silver nitrate per liter is just sufficient to precipitate all the chlorine in an equal volume of a sample, the sample contains 50 grains of chlorine to the gallon of 231 cubic inches. Hence, the chlorine content of a sample may be expressed thus:

$$X=\frac{N}{S}\times 50,$$

where X equals the grains of chlorine per gallon of sample, S equals cc. of original sample tested, and N equals cc. of nitrate of silver solution of 4.101 grams per liter required to just precipitate all the chlorine in the sample.

NOTE.—The sample in dish 3 at the beginning of the chlorine test consisted of more than 50 cc. of total contents, being made up of the original 50 cc. of boiler water, and the amounts of indicators, acid, and alkali added subsequently. However, the reaction for determination of chlorine depends upon the precipitation of all chlorine contained in dish 3, and since none has been either added or subtracted by the addition of the other reagents, the amount of nitrate of silver required to precipitate all the chlorine in the augmented sample is a direct measure of the chlorine content in the original sample of 50 cc. expressed in terms of grains per gallon.

The test for chlorine as described above will determine the chlorine content within a fraction of a grain, and should be employed when testing water from condensers, distillers, and feed tanks, and generally any water known or supposed to contain less than 50 grains of chlorine to the gallon.

For the rough determination of high chlorine content, the graduated measuring bottles may be used as follows: Having made the sample neutral or very slightly alkaline, after the test for alkali, decant into the graduated measuring bottle until the top of the sample is level with the graduation marked O. The tube now contains 5 cc. of the sample. Add one drop of the chromate indicator from bottle 17; slowly add silver nitrate solution from bottle 15; keep shaking the tube. On nearing the full amount of nitrate solution required, the sample will become reddish for an instant, but will turn back to yellow when shaken. Add nitrate solution drop by drop, and as soon as the sample shows a reddish yellow and remains that color when shaken, stop adding nitrate. The reading of the graduated tube at the top of the sample will show the grains of chlorine per gallon. This is because the graduations, beginning from the bottom of the tube, are in increments of 5 cc., and a given volume of a nitrate of silver solution containing 4.101 grams to the liter will just precipitate all of the chlorine in an equal volume of water containing chlorine in the proportion of 50 grains to the gallon. It follows that double the amount of nitrate solution will be required to cause the same reaction in water containing chlorine in the proportion of 100 grains to the gallon, etc.

NOTE.—(a) The fact that one or more reagents must be added to the sample before the silver nitrate solution is added, and the proportional volumes be thereby disturbed, vitiates somewhat the accuracy of the results of this method of test. But as the method is necessarily a rough one at best, the error introduced by adding the reagents will be negligible unless a relatively large quantity of acid or alkali has been required to make the sample nearly neutral.

(b) Using this method, chlorine up to about 900 grains per gallon may be measured. If the sample contains more than this, proceed as follows: Take 10 cc. of the sample and dilute with 90 cc. of distilled water. Take 5 cc. of the diluted sample and proceed as before. Each 5 cc. of silver nitrate added now indicates 500 grains of chlorine to the gallon. Other proportions may be used in a similar manner.

It is important that before collecting samples of water from boilers, tanks, distillers, etc., the receptacle in which the sample is collected be well rinsed out with distilled water or water from the

same boiler, tank, or distiller which is to be sampled. Otherwise precipitates from a previous sample may remain in the receptacle and be redissolved, and the test will give erroneous results. Similarly the dish 3 should be thoroughly washed and dried after each test, to remove traces of previous sample and of the reagents used in testing it; and, generally, before using burettes, beaker, measuring cylinder, etc., with any sample or reagent other than the same with which they were last used, they should be well rinsed out with a quantity of the liquid with which they are about to be used.

The litmus papers are furnished for rough qualitative alkaline or acid determinations. They should be used with caution. When used with water or any other liquid having an affinity for CO_2, the liquid should be boiling, since the presence of CO_2 will cause the color reaction to lag and results may be very misleading.

The subject of ferroxyl-mounts (corrosion indicators) is taken up in the Appendix.

CHAPTER XIV.

CARE AND MANAGEMENT OF BOILERS.

The United States Naval Instructions lay down certain specific instructions for the care, preservation and management of boilers and machinery. These instructions embody the results of experience and good practice up to the time they were written. More extended experience, alteration of design, and military expediency necessitate occasional changes in them.

The essential considerations are: (1) *Safety,* (2) *reliability,* (3) *prevention of deterioration,* (4) *economy.*

Knowledge of engineering and of engineering materials in general is essential, and a thorough understanding of every detail of the particular plant is necessary for its proper care and management.

Routine.—A definite routine of work, inspections and reports prevents omissions, delays and friction among the personnel. The Regulations and Instructions should be gone over thoroughly, and specific times should be designated for carrying out their requirements.

Special Instructions.—Certain special features of the boiler management and machinery operation in the fire-rooms, as well as the necessity for training the fire-room force, will require the posting of special orders and instructions for the guidance of all concerned.

"Frequent" and "Regular" Intervals.—The repeated recurrence of the words "frequent" and "regular" in reference to the examination, overhauling and testing of the machinery is indicative of the necessity for careful periodic examinations, to prevent faults developing or to enable small defects to be discovered before they develop into serious defects.

The particulars outlined below cover many points which arise in the management of the boiler plant.

Damage from Freezing.—Water in boilers and other vessels should not be allowed to freeze in cold weather. Particular care in this respect should be exercised with steam-launch boilers and water jackets of gasoline engines. Damage from freezing frequently occurs, as the result of a fall in temperature during the night after machinery is secured.

Loss by Leakage.—The loss of water due to leaky valves, joints, drains, glands, and jackets would, in many cases, be surprising if calculated. Besides the direct loss of fresh water, there is also, in many cases, a loss from deterioration due to rust formed in the vicinity of the leaks.

Air leaks lower or destroy the vacuum in condensers. Air getting into the feed water through the drains or from any other source is the most potent factor in the internal deterioration of boilers.

Salt Water in the Feed System.—Salt water may get into the feed system in the following ways:

(1) Through leaky condenser (main or auxiliary).

(2) Through evaporator drains.

(3) Through leaky reserve feed tank (manhole gasket or leaky seam).

(4) Through salty water in ship's tanks.

(5) Through bottom blow pipe.

(6) Through evaporator vapor to auxiliary exhaust (where fitted).

(7) Through pumps having connections to drainage system and feed system (where fitted).

(8) Through drains from steam-heated salt-water baths.

The harmful effects of salt water necessitate stringent precautionary measures to prevent its introduction into boilers.

Preservation of Idle Boilers.—Boilers, when not under steam nor open for cleaning, overhauling or examination must be kept quite full of fresh water made sufficiently alkaline to prevent pitting. They must be pumped full within 24 hours of the completion of steaming, and must be so kept until within 24 hours of again raising steam.

Whenever, for a particular reason, it is not practicable to keep idle boilers full of fresh water, the following alternate method must be used for their internal preservation: They must be emptied and their interiors must be dried out as thoroughly as possible. Open trays, of as large capacity as practicable, and filled to about half their height with quicklime, must be introduced through the manholes into the upper and lower parts of each boiler. They must then be closed air-tight, and special precautions must be taken to prevent any moisture from entering the interiors while they are being thus treated. If necessary, joints of the feed and blow systems

must be broken and adjacent sections of steam piping must be shut off and their drains be left open.

Whenever the boilers are open for cleaning and overhauling, their interiors must not be allowed to remain in a damp condition longer than required to accomplish the necessary cleaning. The cleaning and washing out of the interiors must be completed as soon as possible after opening, and then the boilers must be closed at once and filled. If, to complete repairs or overhauling of the internal fittings, it is necessary to keep the boilers open for a considerable time after they have been washed out, their interiors must be thoroughly dried out and kept dry until they can be closed and filled.

To prevent corrosion while exposed to the atmosphere, especially during periods of wet weather, the fire sides of the tubes and other heating surfaces, fittings, and parts within the furnaces, combustion spaces and uptakes of idle boilers must be kept free from moisture. Light fires in small stoves or pans placed in the furnaces or ash pits may be used to dry out empty or idle boilers.

The furnace and ash-pit doors, and the dampers in the uptakes, of all idle boilers must be kept closed. The furnaces of empty boilers must not be primed. When practicable, the funnels and escape pipes must be kept covered when all of the boilers connecting to them are idle.

Precautions when Overhauling Boilers.—To prevent accidental scalding of men working inside boilers, all connections through which steam or hot water might enter the boiler must be lashed shut before men are allowed to enter them.

In opening boilers after they have been steaming, the air cock should be opened first to relieve any pressure which might not be shown by the pressure gage. The boiler should be thoroughly ventilated, and the air should be tested with a lighted taper or candle, before anyone enters.

Danger from Scale and Deposits.—Scale on the water surfaces of boilers forms a non-conducting layer and reduces evaporative efficiency. If the scale is thick enough, the intense heat on the fire side will raise the temperature of the metal high enough to weaken it so that it may rupture under the pressure of the steam. Salt, oil, mud and vegetable and animal matter in the water cause scale. Besides scale, grease also causes priming, because it spreads over the surface of the water and resists the escape of steam bubbles through

the surface. The steam collects in spots and bursts through the oil film, carrying the water with it. Vegetable and animal matter also disintegrate and form acids which increase the electrolytic action of the water and hasten corrosion.

The sources of salt in feed water have been mentioned. Muddy and impure water may come from barges or navy yards. Oil gets into the feed water through drains from engines operating with a vacuum.

Boiler water should be pure. Whenever it is necessary to obtain water from shore or from barges, it should be tested, and should not be accepted if impure. Military necessity or other circumstances may, at times, make the use of impure water necessary. In such case, additional caution should be exercised to prevent deterioration.

Changing the Water.—Water in boilers should be changed only when impure, salty or dirty. A boiler on a large battleship contains from nine to eleven or more tons of water, and its loss is a considerable item. Using boilers to trim ship, or as reserve feed tanks, necessitates the shifting of the water level and the introduction of air into the boiler, increasing corrosion, particularly at the water level. The boilers are installed to generate steam and for that purpose only. They must not be used for any other purpose except in case of urgent necessity.

Removal of Impurities.—All devices fitted for the removal of air and impurities in feed water should be kept in constant use. Grease extractors should not be bypassed when dirty, but should be cleaned and the toweling should be shifted as often as necessary. Loofa in feed tanks should be cleaned or removed when dirty. Air and water leaks should be sought and remedied daily.

Test of Water.—The water in all boilers under steam must be tested daily for alkalinity and salinity, using the standard navy boiler water-testing outfit. The water in the feed tanks must be tested every watch. A routine of supplying alkali to the feed water should be established in order that the prescribed degree of alkalinity may be maintained.

The corrosive properties of the boiler water may, to some extent, be determined by placing a piece of clean steel of the same composition as that of the boiler in a sample of boiler water in a bottle for at least 24 hours. Any especially harmful ingredients will cause rust spots to form on the steel in less than 24 hours.

Water Treatment.—It has been shown that boiler water must be kept alkaline in order to reduce corrosion. The alkalinity must be maintained at that prescribed by the Bureau of Steam Engineering. The alkali may be put into the boiler by means of a short reducing coupling on the suction of an auxiliary feed pump, or it may be put into the feed tanks. If lime is used, it must be dissolved in cold pure water, and the precipitated residue must be thrown away. Only the water of the solution is used. After boilers have been overhauled, the alkali may best be put into the boiler direct, through manholes or handholes. When water has remained in a boiler a few weeks, the alkali settles to the lower parts and the water will show a lower percentage of normal alkaline solution than actually exists in the boiler. The water should be circulated by means of an auxiliary feed pump to stir up the alkali before the weekly test is made.

Periodical Cleaning.—Boilers should be examined and, if necessary, cleaned and overhauled at regular intervals. The type of boiler, conditions of service, locality in which the ship has remained, age of the boiler, and many other special circumstances will determine the frequency of such cleaning and overhauling. The engineer officer is responsible for the condition of the boilers, and is the judge as to the advisability of overhauling them. Under average conditions, the interval should be about 700 hours of steaming. Fire sides are cleaned as practicable while steaming, as by blowing tubes, etc.

Cleaning Routine.—Whenever a boiler is laid up for overhauling, a routine of cleaning should be followed. The routine must be such as to include every part of the boiler. A good procedure in overhauling the boilers is as follows;

(a) Clean fire sides and everhaul all furnace fittings, brick-work, baffling and fire parts.

(b) Empty, open and wash out the water spaces with fire hose.

(c) Clean and inspect the water side and internal fittings.

(d) Rinse out with fresh water and close the boiler.

(e) Overhaul all valves, gages, cocks and other external fittings as rapidly as possible; then fill boiler with alkaline fresh water.

(f) Examine and repair, as required, all parts of the lagging, casing and seating.

(g) Apply water-pressure test for tightness of valves, gaskets, etc.

(h) Test for tightness under steam, including tightness of casing.

(i) Adjust safety-valves.

Ashes and soot should be removed from the furnaces as soon as practicable after the fires are allowed to die out. If they are allowed to remain long in the ash pans, or on furnace floors, and against boiler casings, moisture may get into them and cause corrosion.

Water should not be used in the ash pans except when absolutely necessary to prevent warping and to prevent the formation of clinkers. The lower parts of boilers, such as the seatings, lower drums and lower parts of the casing, need particular attention to prevent corrosion.

Scale on the outside of the tubes is best removed while the boiler is hot, by using an air blast or steam blast to dislodge it. If allowed to remain until the boiler is cold, it may come off with difficulty.

A hot steam blast should in no case be directed against cold tubes of boilers.

Examination of Tubes.—Boiler tubes should be examined frequently on the fire side. The tubes next to the furnace space are most liable to bulge and warp. Fouling, both internal and external, causes unequal heating, with consequent unequal stresses resulting in distortion. Distorted tubes should be examined and, if bulged or blistered considerably, should be removed.

Securing Tubes.—All tubes of water-tube boilers, except Field tubes, should be flared at the ends to prevent their pulling out of the tube plates or headers. The tubes must extend through the plates into which they are expanded about $\frac{3}{16}''$, and the flaring should be materially greater than the hole into which the tube is expanded.

Particular attention should be paid to tubes in boilers of the bent-tube type, because these tubes under pressure tend to pull out of the tube plates. Tubes so badly worn at the ends that the bevel is worn down to the plate should be renewed. In renewing tubes, it is necessary that the hole for the tube be bored smooth and cylindrical, and that the edges be rounded slightly to give a good holding surface and to prevent cutting of the tube. The tube must be expanded evenly into the tube hole.

Protection of External Parts.—The external parts of the boilers, such as the tops, uptake casings and back casings, are the most inaccessible and most easily neglected, though they frequently need most attention. Water dripping from drains, sweating of pipe lines, and salt water from hoses, splashed on the casing result in corrosion. Paper and trash accumulate quickly on the tops of boilers and in the bilges back of them, unless due vigilance is exercised to prevent their accumulation. The tendency of the fire-room force to stow tools and gear back of boilers should be discouraged. All gear, spare parts, etc., necessary to be stowed in the fire-rooms should be in boxes on the bulkheads. When ashes have to be stowed in the fire-rooms, canvas or boards should be used to prevent the ashes from getting against the boiler casings and bulkheads.

The smoke-pipe guys must be adjusted with change of temperature, and their turn-buckles must be kept oiled.

Fire-Room Gratings.—The gratings over the fire-room hatches must not be taken off except in case of necessity, and should then be replaced as soon as possible. Material which would obstruct the ventilation, or fall through the gratings and injure the machinery or personnel below, must not be stowed on the gratings.

Record of Examinations.—When the boilers and machinery are examined, a careful record of their condition should be kept in a book and the general condition entered in the steam log. A great deal of trouble, extra work and extra expenditure of time are caused by the lack of a proper record of the performances, repairs and overhauling of boilers and machinery. The records are particularly helpful when a change in detail of engineer officers occurs. Reports of unusual cases of damage and deterioration, and of any occurrences of particular or unusual interest, should be made to the Bureau of Steam Engineering. *Such reports promote improvements.*

Safety-Valves.—The designed load on the safety-valves, that is, the designed steam pressure per square inch at which the safety-valves are set to lift when the boiler is newly built and installed, may have to be reduced on account of deterioration of the boiler due to special causes or to length of service. The frequent examinations, periodical overhauling, and special tests will determine the extent of the reduction necessary. The U. S. Naval Instructions give a definite procedure in the case of worn boilers.

The hand lifting gear must be tested weekly to make sure that the valves do not become frozen on their seats; and when the boilers are under steam, the valves must be lifted weekly by steam. When raising steam in a boiler, its safety-valve must be lifted by steam and, if necessary, adjusted to lift at prescribed pressure before the boiler is connected. If, for any reason, the safety-valves do not lift and reseat properly, they must be put in proper working order without delay. In setting the valves, the three usually installed should be set so that the lifting pressures vary by a pound or so. If all lifted at once, it would be difficult to tell from the sound that all had lifted. It is, however, usually unnecessary to attempt such refinements, as it is rather difficult to set all the valves to lift at exactly the same pressure, so that there will usually be the necessary difference.

Pressure-gages fitted on boiler fronts are frequently deranged by the heat and give false readings; therefore, when testing safety-valves, it is necessary that the Senior Engineer Officer assure himself that the readings of the pressure-gages are correct.

The spare springs of safety-valves should be kept dry in the boxes in which they are stowed, and should be oiled if necessary, to keep them from rusting.

Water-Gage Fittings.—Particular care should be given all water-gage fittings. The glasses should be blown through by the water tender of every watch coming on, to make sure that the water communicates through the pipes. Gage cocks must be tested every watch when steaming. Sometimes there is a tendency among the fire-room force to dispense with the routine tests because they start leaks. *The whole theory of tests is that leaks and faults may be discovered in time to prevent deterioration and breakdown.*

Gage Tests.—Boiler steam-gages should be tested at least once every three months, and corrected by comparison with a standard gage or by adjustment with the gage-testing outfit. Vibration, heat, or accidental striking of the gages may introduce errors in their readings. The dial pointer is usually secured to its spindle with a friction fit, and may jar loose. Gages placed on boiler fronts are particularly subject to derangement due to the heat.

Tests of Pressure Parts—Worn Boilers.—The pressure parts of worn boilers, except the tubes, are best tested by drilling holes about ½″ in diameter through the worn parts and measuring the thickness. The holes should be plugged with screw plugs riveted over. The extent of the wearing, such as that due to pitting, can only be

guessed at by eye. If there is any suspicion as to the thickness of the part, the drill test should be made. A careful record of the location of the parts tested, of the original thickness and that after test, together with any special facts of interest in regard to the tests, must be entered in the boiler record and the steam log. Drill tests must be carried out in strict accordance with the Naval Instructions.

Water-Pressure Test.—After general overhauling, or when the boiler has been out of service for a long time, or if, for any reason, a boiler is considered to be weak, a water-pressure test is given the boiler to determine its tightness and the strength of its material. In the U. S. Navy the following is the prescribed procedure:

N. I. 3076. (1) The boiler shall be tested by water pressure at such times as the engineer officer may deem necessary or advisable.

(2) Whenever such test is made to prove the safe strength or the tightness of any riveted, expanded, or other permanent structural joints or parts of a boiler, the following method shall be employed: The water shall be heated to a temperature of not less than 150° F.; and, before applying pressure, the boiler shall be completely filled with water and entirely free from air, and necessary precautions shall be taken to insure that there be no leak past the main or auxiliary stop valves into pipes that may contain steam. The pressure to be applied shall not exceed one and one-quarter times the authorized safety-valve setting unless special directions from the Navy Department, commander-in-chief, or senior officer present are received. For ordinary overhaul of boilers, referred to in Article 3065, Naval Instructions, the hydrostatic pressure described and outlined in "Instructions for care, preservation, and operation of boilers" will be used, as it is not advisable to subject boilers to unnecessary strains except for special reasons. In the case of fire-tube boilers that have been in service longer than two years, the water pressure to be applied shall be limited to 25 per cent greater than the load on the safety-valves. The pressure shall be increased slowly and be very carefully applied, in order that injury may not be caused by over-pressure, particularly if a drill test should have revealed unusual thinness of any parts.

(3) During the application of the water pressure, the boilers shall be carefully examined and proper gages be used, when practicable, to detect any change in form in any of their parts. Should any indication of probably permanent deformation be observed, the test shall cease, and the weak parts shall be strengthened as necessary. If this be not practicable, a new test pressure 20 pounds

below that at which permanent deformation commenced shall be adopted, and the new working pressure shall be that which corresponds to such new test pressure, according to paragraph (2). The load on the safety-valve shall be reduced to the new working pressure.

N. I. 3077. To prove the tightness of all valves, gaskets, and fittings of boilers under the working pressure, the following tests will be made, if practicable, upon the completion of each general overhauling or repair affecting such parts. A water pressure of 10 pounds per square inch less than the load on the safety-valve shall be applied. After attaining this pressure, all connections, including the feed, stop, and check valve, shall be closed and the dropping pressure during a considerable number of hours be noted. If the test be made with water of nearly the same temperature as the boiler and the fire-room, the dropping pressure should not exceed 20 pounds in 24 hours. If there be no leaks in the boiler or its fittings, there will be no change in the boiler pressure other than that due to change in temperature of the boiler or the water, or both. It should be borne in mind that leaky feed valves will give false indications, and that, until gaskets are softened by heat, there may be slight leaks around the plates, which will readily take up under steam pressure. For the latter reason, whenever sufficient time is available, this test should be made after steam has been raised to adjust the safety-valve and the boiler has again cooled down, when this is done in connection with general overhauling. Although hot water searches out leaks with more facility than cold water, the time element included in this test affords opportunity for the water to cool, with consequent contraction in volume and reduction in pressure, giving an appearance of leaks which may not exist. For this reason water used for this test should be as nearly as possible the temperature of the boiler and of the fire-room.

Precautions in Regard to Fuel Oil.—The advent of oil as a fuel for boilers has necessitated certain precautions not required with coal. The precautions place restrictions particularly upon (1) *smoking,* and (2) *open* (naked) *lights.*

The principal source of danger with fuel oil is the explosive vapor which it gives off. This vapor is heavier than air and accumulates in low pockets and bilges. In general, no spark from any source, as from smoking, open lights, etc., must be allowed to get into any compartment where fuel oil is stowed or used. Also, all pipes, tanks

and compartments which have contained fuel oil must be freed from possible accumulations of explosive vapor by steam, water or air blast before anyone is allowed to enter or work on those containers.

Especial care is needed to prevent the accumulation of oil in the fire-room bilges and on the fire-room floors. If the oil is accidentally spilt, it must be wiped up immediately.

No smoking, nor any naked lights, should be allowed near the fuel oil tanks and vents or near the hose through which oil is being taken on board.

The electric fuzes in circuits in compartments where oil is used must be of the enclosed type, and electric lamps must have some type of protective covering around the bulb.

Oil-burning boilers are not now fitted with dampers; but in vessels using both oil and coal, and in oil-burning boilers which have dampers, such dampers must always be wide open when the boiler is under steam.

Steam-Launch Boilers.—Steam-launch boilers are subject to a great deal of wear and tear incident to service, and should be examined frequently both inside and out and repaired as necessary. Particular attention should be given the internal feed pipe, dry pipe, safety-valves, water-gages, and other fittings. If, in emergency or other unavoidable circumstance, salt water is used in launch boilers, they should, as soon as practicable after such use, be thoroughly cleaned and scaled on the inside. Launch boilers contain a comparatively small amount of water, and any deposit from salt water collects more quickly and causes more rapid overheating and consequent distortion than in boilers containing a greater relative quantity of water. If the boiler is of the Ward drop-tube type, scale is especially harmful, as it collects in the bottoms of the drop tubes and in a short time causes rupture from overheating.

Draining of Water Containers.—All pipes and cylinders, for either water or steam, and all condensers and other water containers, must, when not in use, be well drained. Water remaining in them may cause rusting in the containers themselves, or may leak and cause rusting in the vicinity of the leak outside the container. A more probable and more serious danger is that from water-hammer when steam or water is again turned into the piping.

Equalization of the Work of Boilers.—A record is kept of the number of hours under steam of every boiler, from the date of commission of the ship. From this record it is possible to equalize the

work among the boilers and thus obtain for each the same average life.

Increasing Speed with Fire-Tube Boilers.—Cylindrical fire-tube boilers, on account of their construction, will not stand the unequal contraction and expansion and wear on the metal when the boiler is forced at a rate much above that of natural draft. Leaks result; so that, when it is necessary to increase speed, additional boilers should be used. Here, as in many cases of emergency or military necessity, a rule cannot be strictly followed, but the results of forcing should be understood, and increased vigilance should be exercised, should the necessity for forced draft arise.

Training of Firemen.—In order that the best results may be obtained when the development of the highest power is a matter of great importance, frequent opportunity should be given for training the firemen to work the boilers at their full capacity under both natural and forced draft conditions. With this object in view, and to insure that the boilers in use are being worked at approximately their full capacity, when more careful firing will be necessary than is required under easier or more economical conditions of steaming, no more boilers must be employed upon such occasion than are required for the speed ordered.

Particular attention must be given to the training of the firemen, especially as regards the management of the fires, and all engineer officers and fire-room petty officers must take advantage of every opportunity to instruct the firemen how to burn the fuel in the most economical manner. Every effort must be made to keep the steam pressure and the water level in the boilers constant, to work the fires in the most efficient and systematic manner, and to use to the best advantage all appliances that may be fitted for timing the operations of firing, for regulating the supply of air, and for economizing in any way the expenditure of fuel. The engineer officer must ascertain the most economical rate of consumption of fuel, together with the number of boilers it may be necessary to employ, for any required speed and condition of steaming.

A time firing device is a very efficient means of obtaining uniformity in the firing interval.

When burning coal, careful attention must be given to the management of the fires, to secure the utmost economy and efficiency of combustion. The fires must be maintained at a uniform thickness in all parts of the furnace; this should be about 8″ thick for

natural draft, and from 10″ to 12″ for forced draft. Green coal should be added to the fire at regular and frequent intervals, and should be scattered over the entire surface. An excellent scheme for training new firemen to distribute the coal evenly over the grate is to lay out a space equal to the grate area on the fire-room floor and have them practice shoveling the coal over this model grate. After a little practice, great proficiency is obtained, as the fireman can easily see where he has failed to cover the space properly.

The furnace doors should be kept open only the shortest possible time. Holes in the fire or the accumulation of clinkers in any part of the furnace must be prevented. All lump coal must be broken up before being fired. The fires should be cleaned at regular and frequent intervals, and as often as necessary to keep them in good condition. Care must be taken to remove all clinkers alhering to the grate bars. The necessary cleaning should be done as quickly as possible in order to reduce to a minimum the amount of cold air admitted through the uncovered grate and the furnace door. The uptake dampers should be closed while cleaning fires. The uptake dampers, rather than the ash-pit doors, should be closed when necessary to temporarily check the rate of combustion; the closing of the ash-pit doors is liable to cause the burning or buckling of the bearer bars and grate bars. The use of water in the ash pans is unnecessary under ordinary conditions, and should not be resorted to except when necessary to prevent clogging of the grates by excessive clinkers. *It should be thoroughly impressed upon all the fire-room force that the primary object of the damper is to check the draft and control the output of steam and that it should always be used for that purpose. Any other means of controlling the steam pressure except the starting of additional auxiliary machinery or the lifting of the safety-valves may result in harm to the boiler.*

Unequal Expansion.—Probably the most important point in connection with the operation of boilers, yet the one most often forgotten, is the harmful effect of unequal expansion and contraction, due to difference of temperature, upon the strength and life of the boiler. The excessive strains taking place in metals and materials on account of local variation of temperature are of such common occurrence in metallurgy and every-day life as to need no comment. In spite of all precautions to prevent unequal contraction and expansion while the boilers are in operation, their entire prevention is impossible. The desirability of reducing their harm-

ful effects to a minimum should be apparent. The less rigid the construction of the boiler, the less is it affected by varying temperatures. Hence, Scotch boilers require more time in which to generate steam than do water-tube boilers. Experience shows that about eight or ten hours is desirable when raising steam in Scotch boilers, while about two hours is a good rule for water-tube boilers. If brick-work is new, more time is necessary to dry out the mortar and cement. Holes in the fires, especially at the front of the grate between doors, frequently cause great strains and leaky nipples (in B. and W. boilers) over them.

Precautions in Raising Steam.—Before starting fires in any boiler, all valves and other fittings such as drain cocks, bottom and surface blow valves, handhole and manhole plates not intended to remain open, must be examined to see that they are tightly closed. The safety-valves, boiler stop valves, feed check and stop valves and water-column gage and test cocks must be tested, to see that they are all in proper working order. It must be made certain that the valves and pipes leading to the pressure-gages and water-gages are wide open. The water shall be brought to a height that is slightly below the normal steaming level. The air cock must remain open while the water is being run down and while steam is being raised, and must be closed after steam has formed.

While steam is being raised in a boiler, close attention must be given to all the boiler fittings and feed arrangements, to insure that they are in all respects in proper working order. Special care must be taken, in setting up the nuts of handhole and manhole fittings, that no greater leverage is applied than the proper spanner provided for that purpose. Ash-pit doors of automatic or balanced type must always be left mounted while boilers are under steam. The boilers should be connected to the steam line when there is a difference of pressure not exceeding 10 pounds, and the boiler stop valve should at first be only slightly opened, to allow the pressures in the steam line and in the boiler to equalize gradually. After the pressures have equalized, the stop valve may be further opened gradually to such extent as required.

Whenever steam is raised in a boiler, in order to insure that the safety-valves are in good working order and to ascertain the exact pressure at which they will lift, the steam pressure must be allowed to rise until these valves should lift if properly adjusted. This may be done after the boiler has been connected, if more con-

venient, but the boiler must not be continued in use unless the safety-valves have been correctly adjusted.

The safety-valves are adjusted by trial and error by setting up or easing off on the compression nut or running the huddling ring up or down as necessary to increase or decrease the lifting and re-seating pressure. If the pressure is seen to go appreciably higher than that at which it is desired the valves should lift, the damper is closed and the safety-valve is lifted by the hand gear, in case the pressure cannot be checked by means of the damper. When the valve lifts, the pressure drops until the valve reseats. To lift the valve again, the damper is opened and the pressure rises. Each time the valve lifts, the pressure is noted and slight changes are made in the adjustments. When one valve of the set is regulated as closely as possible to the load desired, it is gagged and the others of the set are adjusted in a similar manner.

Feed-Water Heaters.—The temperature of the feed water entering the boiler should be kept as high as possible, in order that fuel may be economized. The factors entering into the temperature of the feed water as it leaves the feed heater are the temperature of the water in the feed tank and the speed of the feed pumps. The quantity of drain water entering the feed tank, the temperature of the circulating water in the condenser, and the speed of the circulating pump regulate the temperature of the water in the feed tank.

It must be remembered, however, that feed heating does not result in economy if the back pressure on the auxiliary exhaust is raised to such a point as to materially decrease the efficiency of the auxiliary machinery. This caution should be particularly heeded in all cases where turbine-driven auxiliaries are installed.

Feed heating is always economical, however, if steam that would otherwise be wasted is used for feed heating.

Banked Fires.—In water-tube boilers, banked fires cause unequal heating of the parts of the boilers, with the resulting harmful effects, such as leaky seams and joints and burnt grate bars, and should not be allowed except in emergency or as a military necessity. In ordinary service, where it is not expected to use the boilers again for about twelve hours or more, it is better for the boilers and more economical to allow fires to die out.

If the boilers are to be used again in a few hours, it is better to keep light spread fires and check the draft.

Banked fires are harmful in a much less degree in fire-tube boilers than in water-tube boilers, as the large quantity of water contained in the shell and surrounding the furnaces helps to equalize the temperature.

Hauling Fires.—Fires must not be hauled except to prevent damage to a boiler in case of emergency. When steam is no longer required, the fires must be allowed to die out in the furnaces, with the dampers, furnaces and ash pits closed.

Whenever any water-tube boiler is suspected of being injured to such an extent that the fires should be hauled, the fire doors must not be opened to commence this operation until the safety-valves have been lifted, stop valves closed, and the steam pressure reduced to less than 50 pounds. While this reduction is being effected, the fire and ash-pit doors must be kept closed and the extinguishers, if fitted, must be used to quench the fire.

Supply of Feed.—Boilers under steam should be fed at a regular rate for a definite power developed. Theoretically, at a constant speed of the engines, with boilers all of the same power and generating the same quantity of steam, it should be possible to regulate the feed check valves to a certain opening and not change this opening until the speed or number of boilers is changed. Actually, on account of the varying proficiencies of the firemen and the conditions of the boilers, no two boilers generate the same quantity of steam for any considerable time, so that it is necessary for the water-tenders continually to be making small adjustments of the check valves to keep the water at a constant level. If careful attention is given to the proper feeding of the boiler, any difficulties arising in the feeding will be detected in time to prevent accident and injury.

Low Water.—Low water in a steaming boiler is of frequent occurrence, and is usually the result of one of the following causes:

1. Inattention of the water-tender or the diverting of his attention to other duties.
2. Faulty action of the feed pumps.
3. Leaks in the feed discharge line.
4. Hot or low water in the feed tanks.
5. Defective check valve.
6. Water gages giving false indications.
7. Poor evaporation by the boiler (at high speeds) causing priming.

When the water in a water-tube boiler drops out of sight in the glass and remains out of sight, the fires must be hauled and the boiler cut out. The feed check valve should be closed to prevent cold water striking the parts which will become overheated. The stop valve should be closed to prevent steam rushing in from other boilers when the safety-valve is lifted to relieve the pressure on the weakened boiler. The fires should be damped before they are hauled, and then the boiler casing should be completely closed to prevent any air from getting to the heated parts until they are thoroughly cooled. In oil-burning boilers the burners should be shut off under such circumstances.

Ash-Pit Doors.—When boilers are under steam, the automatic ash-pit doors should be in place and be so adjusted that they will close properly in case of the rupture of any pressure part of the boiler. The infrequency of emergencies necessitating automatic safety devices such as this, makes the fire-room force forgetful of their importance, and it is frequently necessary to remind them of their proper handling and care.

Boiler Accidents.

In all cases of accident to boilers or machinery, every endeavor shall be made to localize the injury. The compartment involved should be isolated to prevent escaping steam from getting into other compartments and interfering with proper attendance of other boilers or machinery in use. All men on duty must remain at their proper stations, give strict attention to the machinery in operation and avoid the inattention sometimes due to excitement which may lead to further damage. When considerable leaks of steam occur in a fire-room, the upper part of the compartment is generally filled with steam and men must not be allowed to go up the fire-room ladders at such times on account of the great danger of their being seriously injured or overcome by inhaling the steam. The best avenue of escape, if it becomes necessary to abandon the compartment, is through an opening at the level of the fire-room floor plates.

Whenever a serious steam leak occurs in a tube or other pressure part of the boiler, the following procedure should be followed:

1. Open safety-valves as quickly as possible to relieve the pressure.
2. Close the boiler stop valve.
3. Notify engine-room force and tell them to keep plenty of water in feed tanks.

4. Deaden fires (shut off burners if burning fuel oil).

5. Keep ash-pan doors and furnace doors closed until the steam pressure is reduced to about 50 pounds or less. (The ash-pan doors will have closed automatically if the rupture occurred in a part surrounding the furnace.)

6. Keep the blowers going and increase their speed to drive the steam out of the fire-room.

7. Leave the dampers open.

8. Keep the feed check valve open, and also put on auxiliary feed, if needed.

9. Haul fires, and then close the boiler and allow it to cool slowly.

If the leak is so bad that the water level cannot be maintained, the feeding of the boiler should be stopped. If the level can be maintained, an auxiliary feed pump should be started to feed the injured boiler, in order that the other boilers may not suffer lack of water on account of the extra feed to the injured one.

The Use of Fuel Oil.

N. I. 3122. (1) The principal points requiring especial attention in working fuel-oil installations are:

(a) *The Oil Pressure.*—This in great measure governs the rate of burning the oil, and shall be maintained as nearly constant as possible. As far as practicable, the pulsation from the pumps shall be removed from the oil before it reaches the burners. This is accomplished by the use of air chambers fitted on the discharge side of the pumps and elsewhere in the piping system. The pressure shall be regulated according to the amount of oil required to be burned. For small variations in the rate of steaming, without changing the number of burners in use, the corresponding change in the quantity of oil supplied shall be made by altering the oil pressure and not by changing the amount of opening of the burners, unless a readjustment is necessary to secure a satisfactory spray.

(b) *The Air Supply.*—This varies according to the amount of oil to be burned, and shall be carefully regulated to maintain a steady flame of about the same size from each burner and an amount of smoke that is just visible at the top of the smoke-pipe. Too little air will produce excessive smoke, and may cause flaming through the slots of the air cones and overheating of the cones themselves. Too much air, while it may prevent smoke, will reduce the efficiency of the boiler. The proper regulation of the velocity with which the air

is admitted to the burners is important in connection with preventing panting of the boilers, and may be accomplished by varying the openings through the slots in the cones when they are fitted with a movable register for this purpose. When not so fitted, the necessary regulation shall be accomplished by varying the air prêssure in the fire-room by means of altering the speed of the fire-room blowers.

(c) *The Temperature of the Oil.*—The oil is heated to make it thin or fluid enough for efficient spraying at moderate pressures. It is found by experiment that considerable increase in fluidity is obtained by heating the oil to from 150° to 175° F., but above the latter temperature there is no considerable change. If heated much beyond 175° F., there is danger of breaking down the oil and clogging the heaters, strainers, burners, or pipes with the solid particles of carbon thus produced. It is dangerous to heat the oil above its flash point, because if a leak occurs the oil will issue in a flame.

(2) Upon starting fires in a boiler, care shall be taken before lighting fuel-oil burners to insure that the furnace and ash pit are clear of oil and well ventilated; and, in order to avoid a possible back flash, the fireman shall stand well clear of the sight-holes and other openings in the furnace front. In lighting burners in addition to those required for raising steam, the oil shall not be turned on until the blowers have been started and the furnace has been cleared of gas. Similarly, in shutting down, the blowers shall be kept running until all the burners have been shut off. Should a burner become extinguished accidentally, the cause may be due to (a) water mixed with the oil coming from the oil tanks, or from leaky heaters; (b) solid matter choking the burner, due either to fault of the strainers or to carbonizing of the oil in the burner; or (c) water passing over with the oil from the tanks or air chambers on the pumps or oil line. When a burner is choked and cannot be cleared by temporary alterations of the spindle adjustment, it shall be removed at once and be thoroughly cleaned. The cleaning shall be very carefully done, care being taken that the outlet holes are not roughened, enlarged, or altered in shape. Burners shall never be left in place disconnected.

(3) When heaters are fitted, special effort shall be made to detect promptly any leaks from the oil to the steam side of the heater. Such leaks allow the oil to pass directly to the boiler water, and, in order to prevent this, the steam pressure on the heater shall

be kept higher than the oil pressure, when practicable. At least once during each watch the drain from the oil heaters shall be tested for the presence of oil, and if oil be found, the heater shall be drained and disconnected at once.

(4) *Boilers Burning Coal and Oil.*—When boilers are fitted to burn oil in combination with coal, it shall be borne in mind that the installation is designed to obtain the full power from the boilers when burning coal alone. The oil is provided to make it possible to maintain production of steam on prolonged full-power runs after the coal fires become dirty, or when the trimming of the coal to the fire-rooms becomes difficult. Therefore, in order to prevent undue forcing when burning both coal and oil, the rate of burning the oil shall not be allowed to exceed 15 pounds per square foot of grate surface per hour. In burning oil with coal, special attention shall be paid to the opening of the ash-pit doors for regulating the quantity of coal burned. When the fires are clean, these doors shall be nearly closed; and their opening shall be gradually increased as the fires become dirty. The fires shall be worked so that the grate is well covered, with no holes; and they shall be of moderate thickness and of even surface. Care shall be taken in handling the fire at the front of the furnace to avoid blocking the air cones and overheating the furnace fronts or cones. The coal shall be fed in small quantities at a time, and the fire doors shall be kept open as short a time as possible. The fire shall be cleaned as would be done when burning coal alone; and, while it is being cleaned, the burners in that vicinity shall be shut off. The air pressure and the supply of coal and oil shall be carefully regulated, so as to produce the most efficient combustion of both fuels, with a minimum of smoke. Should excess smoke occur, the cause may be (a) fires too heavy; (b) insufficient air pressure in the fire-room or improper opening of air register; or (c) ash-pit doors open too wide, or holes in the fires, thus preventing a sufficient proportion of air passing through the air cones.

Use of Bottom Blows.

An increase in the salinity of the feed water in any part of the feed system should be investigated immediately and the cause, if possible, be removed. It will be found generally that the boiler water will show at least a few grains of salt per gallon when every part of the feed system is apparently in perfect condition. The

general condition of the boilers and boiler fittings, and the age of the boilers, will determine the percentage of salt which it is impossible to avoid. An increase in the quantity of salt under given conditions is an indication that something is wrong. Whether or not the increase of salt can be avoided will determine the necessity and frequency of the use of the bottom blow valves. The bottom blows are for the purpose of decreasing the quantity of solid matter in the boiler under steam, whether the solid matter is salt or some other impurity. Under normal conditions, it seldom is necessary to open the bottom blows. Whenever they are used, they should be cracked to equalize the pressure in the blowpipe and boiler, and then quickly be opened wide and left open for a few seconds, and then quickly closed. The amount of blow-down is determined by a comparison of the water levels in the gage glass before and after blowing.

Emptying Boilers.

From what has been said repeatedly about the harmful effects of sudden changes of temperature, it is evident that the only proper way to empty a boiler of hot water is to allow the boiler and water to cool slowly and then to run down or pump out the boiler. In this connection, attention may properly be called to the somewhat similar harmful effects of quickly reducing the pressure in emergency by means of the safety-valves. If possible, pressures and temperatures should be reduced slowly.

CHAPTER XV.

BOILER TESTS.

The following rules for conducting boiler trials, code of 1899, have been adopted by the American Society of Mechanical Engineers:

I. **Determine at the outset the specific object** of the proposed trial, whether it be to ascertain (a) the capacity of the boiler, (b) its efficiency as a steam generator, (c) its efficiency and its defects under usual working conditions, (d) the economy of some particular kind of fuel, or (e) the effect of changes of design, proportion or operation, and prepare for the trial accordingly.

II. **Examine the boiler**, both outside and inside; ascertain the dimensions of grates, heating surfaces, and all important parts, and make a full record describing the same, illustrating special features by sketches. The area of heating surfaces is to be computed from the surfaces of shells, tubes, furnaces and fire-boxes in contact with the fire or hot gases. The *outside* diameters of water tubes and the *inside* diameters of fire tubes are to be used in the computation. All surfaces below the mean water level which have water on one side and products of combustion on the other, are to be considered as water-heating surface; and all surfaces above the mean water level which have steam on one side and products of combustion on the other, are to be considered as superheating surface.

III. **Notice the general condition** of the boiler and its equipment, and record such facts in relation thereto as bear upon the objects in view.

If the object of the trial is to ascertain the maximum economy or capacity of the boiler as a steam-generator, the boiler and all its appurtenances should be put in first-class condition. Clean the heating surface inside and out. Remove clinkers from the grates and from the sides of the furnace. Remove all dust, soot and ashes from the chambers, smoke connections and flues. Close air leaks in the masonry and poorly fitting doors. See that the damper will open wide and close tight. Test for air leaks either by firing a few shovels of smoky fuel and immediately closing the damper, and observing

the escape of smoke through the crevices, or by passing the flame of a candle over cracks in the brick-work.

IV. **Determine the character** of the coal to be used. For tests of the efficiency or capacity of the boiler for comparison with other boilers, the coal should, if possible, be of some kind which is commercially regarded as a standard. For New England and that portion of the country east of the Alleghany Mountains, good anthracite egg coal, containing not over 10% of ash, and Clearfield (Pa.), Cumberland (Md.) and Pocahontas (Va.) semi-bituminous coals are thus regarded. West of the Alleghany Mountains, Pocahontas (Va.) and New River (W. Va.) semi-bituminous, and Youghiogheny or Pittsburgh bituminous coals are recognized as standards. There is no special grade of coal mined in the western states which is widely recognized as of superior quality or considered as a standard coal for boiler testing. Big Muddy lump, an Illinois coal mined in Jackson County, Ill., is suggested as being of a sufficiently high grade to answer these requirements in districts where it is more conveniently obtainable than the other coals mentioned above. For tests made to determine the performance of a boiler with a particular kind of coal, such as may be specified in a contract for the sale of a boiler, the coal used should not be higher in ash and in moisture than that specified, since increase in ash and in moisture above a stated amount is apt to cause a falling off of both capacity and economy in greater proportion than the proportion of such increase.

V. **Establish the correctness** of all apparatus for weighing and measuring used in the test. These are:

1. Scales for weighing coal, ashes and water.

2. Tanks or water meters for measuring water. Water meters, as a rule, should be used only as a check on other measurements. For accurate work the water should be weighed or measured in a tank.

3. Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc.

4. Pressure gages, draft gages, etc. The kind and location of the various pieces of testing apparatus must be left to the judgment of the person conducting the test, always keeping in mind the main object, *i. e.*, to obtain authentic data.

VI. **See that the boiler is thoroughly heated** to its usual working temperature before the trial. If the boiler is new and of a form

provided with a brick setting, it should be in use at least a week before the trial, so as to dry and heat the walls. If it has been laid off and has become cold, it should be worked before the trial until the walls are well heated.

VII. **The boiler and connections** should be proved free from leaks before beginning a test, and all water connections, including blow and extra feed pipes, should be disconnected, stopped with blank flanges, or bled through special openings beyond the valves, except the particular pipe through which the water is to be fed to the boiler during the trial. During the test the blow off and feed pipes should remain exposed to view.

If an injector is used, it should receive steam directly through a felted pipe from the boiler being tested.

If the water is metered after it passes the injector, its temperature should be taken at the point where it leaves the injector. If the quantity is determined before it goes to the injector, the temperature should be determined on the suction side of the injector; and if no change of temperature occurs other than that due to the injector, the temperature thus determined is properly that of the feed water. When the temperature changes between the injector and the boiler, as by the use of a heater or by radiation, the temperature at which the water enters and leaves the injector and that at which it enters the boiler should be taken. In this case the weight to be used is that of the water leaving the injector, computed from the heat units if not directly measured, and the temperature that of the water entering the boiler.

Let w = weight of water entering the injector.
x = weight of steam entering the injector.
h_1 = heat units per pound of water entering the injector.
h_2 = heat units per pound of steam entering the injector.
h_3 = heat units per pound of water leaving the injector.

Then $w+x$ = weight of water leaving injector, and $x=w\frac{h_3-h_1}{h_2-h_3}$.

See that the steam main is so arranged that water of condensation cannot run back into the boiler.

VIII. **Duration of the Test.**—For tests made to ascertain either the maximum economy or the maximum capacity of a boiler, irrespective of the particular class of service for which it is regularly used, the duration should be at least 10 hours of continuous run-

ning. If the rate of combustion exceeds 25 pounds of coal per square foot of grate surface per hour, it may be stopped when a total of 250 pounds of coal has been burned per square foot of grate. In cases where the service requires continuous running for the whole 24 hours of the day, with shifts of firemen a number of times during that period, it is well to continue the test for at least 24 hours.

When it is required to ascertain the performance under the working conditions of practical running, whether the boiler be regularly in use 24 hours a day or only a certain number of hours out of each 24, the fires being banked the balance of the time, the duration should not be less than 24 hours.

IX. **Starting and Stopping a Test.**—The conditions of the boiler and furnace should be, in all respects, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same; the water level should be the same; the fire upon the grates should be the same in quantity and condition; and the walls, flues, etc., should be of the same temperature.

Two methods of obtaining the desired equality of conditions of the fire may be used; viz., those which were called in the code of 1885 "the standard method" and "the alternate method," the latter being employed where it is inconvenient to make use of the standard method.

X. **Standard Method of Starting and Stopping a Test.**—Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash pit, and, as quickly as possible, start a new fire with weighed coal and wood, noting the time and the water level * while the water is in a quiescent state just before lighting the fire.

At the end of the test remove the whole fire, which has been burned low, clean the ash pit, note the water level when the water is in a quiescent state, and record the time of hauling the fire. The water level should be, as nearly as possible, the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating the pump after the test is completed.

* The gage glass should not be blown out within an hour before the water level is taken at the beginning and end of a test, otherwise an error in the reading of the water level may be caused by a change of temperature and density of the water in the pipe leading from the bottom of the glass into the boiler.

XI. **Alternate Method of Starting and Stopping a Test.**—The boiler being thoroughly heated by a preliminary run, the fires are to be burned low and well cleaned. Note the amount of coal left on the grate as nearly as it can be estimated. Note the pressure of the steam and the water level. Note the time and record it as the starting time. Fresh coal, which has been weighed, should now be fired. The ash pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start; and the fires should be cleaned in such a manner as to leave a bed of coal on the grates of the same depth, and in the same condition, as at the start. When this stage is reached, note the time and record it as the stopping time. The water level and steam pressure should previously be brought as nearly as possible to the same point as at the start. If the water level is not the same as at the start, a correction should be made by computation, and not by operating the pump after the test is completed.

XII. **Uniformity of Conditions.**—In all trials made to ascertain maximum economy or capacity, the conditions should be maintained uniformly constant. Arrangements should be made to dispose of the steam so that the rate of evaporation may be kept the same from beginning to end. This may be accomplished in a single boiler by carrying the steam through a waste-steam pipe, the discharge from which can be regulated as desired. In a battery of boilers, in which only one is tested, the draft may be regulated on the remaining boilers, leaving the test boiler to work under a constant rate of production.

Uniformity of conditions should prevail as to the pressure of steam, the height of water, the rate of evaporation, the thickness of fire, the times of firing and quantity of coal fired at one time, and as to the intervals between the times of cleaning the fires.

The method of firing to be carried on in such tests should be dictated by the expert or responsible person in charge of the test, and the method adopted should be adhered to by the firemen throughout the test.

XIII. **Keeping the Records.**—Take note of every event connected with the progress of the trial, however unimportant it may appear. Record the time of every occurrence and the time of taking every weight and every observation.

The coal should be weighed and delivered to the firemen in equal portions, each sufficient for not more than one hour's run, and a

fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the last of each portion. It is desirable that at the same time the amount of water fed into the boiler should be accurately noted and recorded, including the height of the water in the boiler, and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the test may be divided into several periods if desired, and the degree of uniformity of combustion, evaporation and economy be analyzed for each period. In addition to these records of the coal and the feed water, half-hourly observations should be made of the temperature of the feed water, of the flue gases, of the external air in the boiler room, of the temperature of the furnace when a furnace pyrometer is used, and also of the pressure of the steam and of the readings of the instruments for determining the moisture in the steam. A log should be kept on properly prepared blanks containing columns for record of the various observations.

When the standard method of starting and stopping the test is used, the hourly rate of combustion and of evaporation and the horse-power should be computed from the records taken during the time when the fires are in active condition. This time is somewhat less than the actual time which elapses between the beginning and end of the run. The loss of time due to kindling the fire at the beginning and burning it out at the end makes this course necessary.

XIV. **Quality of Steam.**—The percentage of moisture in the steam should be determined by the use of either a throttling or a separating steam calorimeter. The sampling nozzle should be placed in the vertical steam pipe rising from the boiler. It should be made of $\frac{1}{2}''$ pipe, and should extend across the diameter of the steam pipe to within $\frac{1}{2}''$ of the opposite side, being closed at the end and perforated with not less than twenty $\frac{1}{8}''$ holes equally distributed along and around its cylindrical surface, but none of these holes should be nearer than $\frac{1}{2}''$ to the inner side of the steam pipe. The calorimeter and the pipe leading to it should be well covered with felting. Whenever the indications of the throttling or separating calorimeters show that the percentage of moisture is irregular, or occasionally in excess of 3%, the results should be checked by a steam separator placed in the steam pipe as close to the boiler as convenient, with a calorimeter in the steam pipe just

beyond the outlet from the separator. The drip from the separator should be caught and weighed, and the percentage of moisture computed therefrom should be added to that shown by the calorimeter.

Superheating should be determined by means of a thermometer placed in a mercury well inserted in the steam pipe. The degree of superheating should be taken as the difference between the reading of the thermometer for superheated steam and the readings of the same thermometer for saturated steam at the same pressure as determined by a special instrument, and not by reference to steam tables.

XV. **Sampling the Coal and Determining its Moisture.**—As each barrow load or fresh portion of coal is taken from the coal pile, a representative shovelful is selected from it and placed in a barrel or box in a cool place and kept until the end of the trial. The samples are then mixed and broken into pieces not exceeding 1″ in diameter, and reduced by the process of repeated quartering and crushing until a final sample weighing about 5 pounds is obtained, and the size of the larger pieces is such that they will pass through a sieve with ¼″ meshes. From this sample two one-quart air-tight glass preserving jars, or other air-tight vessels which will prevent the escape of moisture from the sample, are to be promptly filled, and these samples are to be kept for subsequent determinations of moisture and of heating value and for chemical analysis. During the process of quartering, when the sample has been reduced to about 100 pounds, a quarter to a half of it may be taken for an approximate determination of moisture. This may be made by placing it in a shallow pan, not over 3″ deep, carefully weighing it, and setting the pan in the hottest place that can be found on the brick-work of the boiler setting or flues, keeping it there for at least 12 hours, and then weighing it. The determination of moisture thus made is believed to be approximately accurate for anthracite and semi-bituminous coals, and also for Pittsburgh or Youghiogheny coal; but it cannot be relied upon for coals mined west of Pittsburgh, or for other coals containing inherent moisture. For these latter coals it is important that a more accurate method be adopted. The method recommended by the committee for all accurate tests, whatever the character of the coal, is described as follows:

Take one of the samples contained in the glass jars and subject it to a thorough air-drying by spreading it in a thin layer and exposing it for several hours to the atmosphere of a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill adjusted so as to produce somewhat coarse grains (less than $\frac{1}{16}''$), thoroughly mix and crush the sample, select from it a portion of from 10 to 50 grams, weigh it in a balance which will easily show a variation as small as 1 part in 1000, and dry it in an air or sand bath at a temperature between 240° and 280° F. for 1 hour. Weigh it and record the loss; then heat and weigh it again repeatedly, at intervals of an hour or less, until the minimum weight has been reached and the weight begins to increase by oxidation of a portion of the coal. The difference between the original and the minimum weight is taken as the moisture in the air-dried coal. This moisture test should preferably be made on duplicate samples, and the results should agree within 0.3% to 0.4%, the mean of the two determinations being taken as the correct result. The sum of the percentage of moisture thus found and the percentage of surface moisture previously determined is the total moisture.

XVI. **Treatment of Ashes and Refuse.**—The ashes and refuse are to be weighed in a dry state. If it is found desirable to show the principal characteristics of the ash, a sample should be subjected to a proximate analysis and the actual amount of incombustible material be determined. For elaborate trials a complete analysis of the ash and refuse should be made.

XVII. **Calorific Tests and Analysis of Coal.**—The quality of the fuel should be determined either by heat test or by analysis, or by both.

The rational method of determining the total heat of combustion is to burn the sample of coal in an atmosphere of oxygen gas, the coal to be sampled as directed in article XV of this code.

The chemical analysis of the coal should be made only by an expert chemist. The total heat of combustion computed from the results of the ultimate analysis may be obtained by the use of Dulong's formula (with constants modified by recent determinations), viz.: $14{,}600C + 62{,}000\left(H - \frac{O}{8}\right) + 4000S$, in which C, H, O and S refer to the proportions of carbon, hydrogen, oxygen and sulphur, respectively, as determined by the ultimate analysis.

It is desirable that a proximate analysis should be made, thereby determining the relative proportions of volatile matter and fixed carbon. These proportions furnish an indication of the leading characteristics of the fuel, and serve to fix the class to which it belongs. As an additional indication of the characteristics of the fuel, the specific gravity should be determined.

XVIII. **Analysis of Flue Gases.**—The analysis of the flue gases is an especially valuable method of determining the relative value of different methods of firing or of different kinds of furnaces. In making these analyses great care should be taken to procure average samples, since the composition is apt to vary at different points of the flue. The composition is also apt to vary from minute to minute, and for this reason the drawings of gas should last over a considerable period of time. Where complete determinations are desired, the analyses should be entrusted to an expert chemist. For approximate determinations, the Orsatt or the Hempel apparatus may be used by the engineer. For the continuous indication of the amount of carbonic acid present in the flue gases, an instrument may be employed which shows the weight of the sample of gas passing through it.

XIX. **Smoke Observations.**—It is desirable to have a uniform system of determining and recording the quantity of smoke produced where bituminous coal is used. The system commonly employed is to express the degree of smokiness by means of percentages dependent upon the judgment of the observer. The committee does not place much value upon a percentage method, because it depends so largely upon the personal element; but if this method is used, it is desirable that, so far as possible, a definition be given in explicit terms as to the basis and method employed in arriving at the percentage. The actual measurement of a sample of soot and smoke by some form of meter is to be preferred.

XX. **Miscellaneous.**—In tests for purposes of scientific research, in which the determination of all the variables entering into the test is desired, certain observations should be made which are, in general, unnecessary for ordinary tests. These are the measurements of the air supply, the determination of its contained moisture, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, and (by condensation of all steam made by the boiler) of the total heat imparted to the water.

As these determinations are rarely undertaken, it is not deemed advisable to give directions for making them.

XXI. **Calculations of Efficiency.**—Two methods of defining and calculating the efficiency of a boiler are recommended. They are:

1. Efficiency of the boiler $= \dfrac{\text{heat absorbed per lb. combustible}}{\text{calorific value of 1 lb. combustible}}$.

2. Efficiency of the boiler and grate $= \dfrac{\text{heat absorbed per lb. coal}}{\text{calorific value of 1 lb. coal}}$.

The first of these is sometimes called the "efficiency based on combustible," and the second the "efficiency based on coal." The first is recommended as a standard of comparison for all tests, and this is the one which is understood to be referred to when the word "efficiency" alone is used without qualification. The second, however, should be included in a report of a test, together with the first, whenever the object of the test is to determine the efficiency of the boiler and furnace together with the grate (or mechanical stoker), or to compare different furnaces, grates, fuels or methods of firing.

The heat absorbed per pound of combustible (or per pound of coal) is to be calculated by multiplying the equivalent evaporation from and at 212° per pound combustible (or coal) by 970.4.

XXII. **The Heat Balance.**—An approximate *heat balance*, or statement of the distribution of the heating value of the coal among the several items of heat utilized and heat lost, may be included in the report of a test when the analyses of the fuel and of the chimney gases have been made. It should be reported in the following form:

* The factor of evaporation should be computed as follows: For wet steam, find from the steam tables the heat of the liquid, usually given above 32° F., and correct for temperature of feed. Multiply the latent heat of evaporation by the quality. Add these two quantities together and divide by the heat of evaporation of steam at atmospheric pressure.

* For superheated steam, simply substract from the total heat the excess of feed over 32° F. and divide as before.

* Made in Bureau of Steam Engineering.

HEAT BALANCE, OR DISTRIBUTION OF THE HEATING VALUE OF THE COMBUSTIBLE.

TOTAL HEAT VALUE OF ONE POUND OF COMBUSTIBLE, B. T. U.

	B. T. U.	Per cent.
1. Heat absorbed by the boiler = evaporation from and at 212° per pound of combustible × 970.4		
2. Loss due to moisture in coal = (per cent of moisture referred to combustible ÷ 100) × $[(212 - t) + 970.4 + 0.48 (T - 212)]$; ($t$ = temperature of air in the boiler room, T = that of the flue gases)		
3. Loss due to moisture formed by the burning of hydrogen = (per cent of hydrogen to combustible ÷ 100) × 9 × $[(212 - t) + 970.4 + 0.48 (T - 212)]$		
4. * Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × $(T - t)$		
5. † Loss due to incomplete combustion of carbon = $\frac{CO}{CO_2 + CO} \times \frac{\text{per cent C in combustible}}{100} \times 10{,}150$		
Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, and to radiation, and loss unaccounted for. (Some of these losses may be separately itemized, if data are obtained from which they may be calculated).		
Totals	....	100

* The weight of gas per pound of carbon burned may be calculated from the gas analysis as follows:

$$\text{Dry gas per pound of carbon} = \frac{11CO_2 + 8O + 7(CO + N)}{3(CO_2 + CO)},$$

in which CO_2, CO, O and N are the percentages by volume of the several gases. As the sampling and analysis of the gases in the present state of the art are liable to considerable errors, the result of this calculation is usually only an approximate one. The heat balance itself is only approximate for this reason, as well as for the fact that it is not possible to determine accurately the percentage of unburned hydrogen or hydro-carbons in the flue gases.

The weight of dry gas per pound of combustible is found by multiplying the dry gas per pound of carbon by the percentage of carbon in the combustible, and dividing by 100.

† CO_2 and CO are respectively the percentages by volume of carbonic acid and carbonic oxide in the flue gases. The quantity 10,150 equals the number of heat units generated by burning to carbonic acid one pound of carbon contained in carbonic oxide.

XXIII. **Report of the Trial.**—The data and results should be reported in the manner given in either one of two tables.

These tables are not given here. The forms issued by the Bureau of Steam Engineering intended for the same purpose are given, as follows:

S. E. Form No. 104-2.

DESCRIPTION AND DIMENSIONS OF BOILER AND APPURTENANCES.

Type of boiler..
Diameter of shell..........; top drum........; bottom drum........
Length of shell............; top drum........; bottom drum........
Tubes, number.....; diameter, outside....; length....; thickness....
Furnace, kind of..
Furnace, length.............; width............; height.............
Grate surface, length...........; width...........; area............
Heating surface, area................; ratio to grate.................
Per cent water-heating surface.....; per cent superheating surface....
Grate bars, kind..
Grate bars, width of air spaces......; ratio of grate to air space......
Smoke-pipe, area..........; height.........; ratio to grate..........
Water space..................; steam space........................
Weight of boiler and all fittings except uptakes and smoke-pipe:
Without water ....
Water ....
Total with water...
Total weight per square foot of grate surface........................
Total weight per square foot of heating surface......................
Blower engines, kind........; dimensions of cylinders....×....×....
Blower fan, kind.............; diameter.............; width........
Area of blower inlet.......................; outlet.................
Feed heater, kind..
Feed heater, area of surface.......................................
Economizer, kind ....
Area of surface...
Air heater, kind..
Area of surface...
Feed pumps, kind...........; dimensions of cylinders....×....×....
Other boiler appurtenances ....

S. E. Form No. 104-3.

DESCRIPTION OF APPARATUS.

(a) Method of weighing water ....
(b) Method of weighing fuel ....
(c) Method of determining the amount of moisture in steam:
Kind of calorimeter used.............................
Distance of calorimeter from boiler.........................
Size, shape and description of sampling nozzle................
(d) Method of taking temperature of and sampling flue gases........
(e) Condition of boiler before and after test.......................

S. E. Form No. 104-4.

Number of test.. ... ..
1. Date of test..
2. Duration of test...............hrs...............................
3. Kind of fuel...
4. Kind of start...
5. State of weather...

Average Pressures.

6. Barometer ....ins............................. .
7. Steam pressure by gage.........lbs...............................
8. Force of draft at base of pipe....ins. of water.................. .
9. Force of draft in furnace........do...............................
10. Force of draft in ash pit.........do...............................
11. Revolutions of blower...

Average Temperatures.

12. External air ....degrees F...........................
13. Fire-room ....do...............................
14. Steam ....do...............................
15. Feed water entering heater......do...............................
16. Feed water entering economizer..do..............................
17. Feed water entering boiler.......do...............................
18. Air entering ash pit.............do...............................
19. Escaping gases from boiler......do...............................
20. Escaping gases from economizer..do..............................

Fuel.

21. Kind of ....
22. Weight of wood used in lighting fires.............lbs...............
23. Weight of coal as fired *........................lbs...............
24. Moisture in coal..........................per cent..............
25. Weight of dry coal consumed....................lbs...............
26. Weight of ash and refuse........................lbs...............
27. Weight of combustible consumed................lbs...............
28. Per cent of refuse in dry coal..................................

Fuel per hour.

29. Coal consumed per hour..........................lbs...............
30. Dry coal consumed per hour.....................lbs.... ....
31. Combustible consumed per hour.................lbs...............
32. Coal consumed per hour per sq. ft. G. S............lbs..............
33. Dry coal consumed per hour per sq. ft. G. S.......lbs..............
34. Combustible consumed per hour per sq. ft. G. S.....lbs...............

* Including equivalent of wood used in lighting fires.

S. E. Form No. 104-5.

Number of test.. ....

35. Coal per hour per sq. ft. H. S....................lbs..............
36. Dry coal per hour per sq. ft. H. S..................lbs..............
37. Combustible per hour per sq. ft. H. S.............lbs..............

Quality of Steam.

38. Per cent of moisture in steam......................................
39. Degrees of superheating..
40. Quality of steam (dry steam = 100).................................

Water.

41. Total weight of water fed to boiler *.............lbs..............
42. Water actually evavorated, corrected for quality of steam (40 by 41)..........................lbs..............
43. Factor of evaporation..
44. Equivalent water evaporated into dry steam from and at 212° (42 by 43).......................lbs..............

Water per Hour.

45. Water evaporated per hour, corrected for quality of steam .... lbs..............
46. Equivalent evaporation from and at 212° ....
47. Equivalent evaporation from and at 212° per sq. ft. G. S....................................lbs.............
48. Same per sq. ft. of heating surface...............lbs..............

Economic Results.

49. Water apparently evaporated under actual conditions per lb. of coal as fired (41 ÷ 23)........lbs..............
50. Apparent equivalent evaporation from and at 212° per lb. of coal including moisture (44 ÷ 23)....lbs..............
51. Equivalent evaporation from and at 212° per lb. of dry coal (44 ÷ 25)..........................lbs..............
52. Equivalent evaporation from and at 212° per lb. of combustible (44 ÷ 27)......................lbs..............
53. Efficiency of boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of 1 lb. of combustible. (See Sheet No. 6).......................
54. Efficiency of boiler, including grate; heat absorbed by the boiler per lb. of dry coal, divided by the heat value of 1 lb. of dry coal. (See Sheet No. 6)................

Remarks and Observations.

55. Principal data taken every..
56. Percentage of smoke as observed...................................
57. Method of observing same..
58. Kind of firing (spreading, alternate or coking)...................
59. Average thickness of fires..
60. Average intervals between firings for each furnace during time fires were in normal condition.....................
61. Average interval between times of breaking up....................
62. Efficiency of firemen; expert, average or poor....................

* Corrected for inequality of water level and steam pressure at beginning and end of test.

S. E. Form No. 105-6.

FUEL AND GAS ANALYSES.

PROXIMATE ANALYSIS OF FUEL.

	Coal.	Combustible.
	Per cent.	*Per cent.*
Fixed carbon	....	....
Volatile matter	....	....
Moisture	....	....
Ash	....	....
Total	100.00	100.00
Sulphur separately determined	....	....

ULTIMATE ANALYSIS OF DRY FUEL.

	Coal.	Combustible.
	Per cent.	*Per cent.*
Carbon (C)	....	....
Hydrogen (H)	....	....
Oxygen (O)	....	....
Nitrogen (N)	....	....
Sulphur (S)	....	....
Ash	....	....
Total	100.00	100.00
Moisture in sample of fuel as received	....	....

ANALYSIS OF ASH AND REFUSE.

	Per cent.
Carbon	....
Earthy matter	....

CALORIFIC VALUE OF FUEL.

Kind of calorimeter used..

Calorific value by calorimeter, per pound of dry coal............B. T. U

Calorific value by calorimeter, per pound of combustible........ Do.

Calorific value by analysis, per pound of dry coal.............. Do.

Calorific value by analysis, per pound of combustible........... Do.

ANALYSES OF DRY GASES.

	Per cent.
Carbon dioxide (CO_2)	....
Oxygen (O)	....
Carbon monoxide (CO)	....
Hydrogen and hydrocarbons	....
Nitrogen (N) (by difference)	....
Total	100.00

For naval purposes, boilers are generally tested in order to determine: (a) The evaporative efficiency of different types under the same conditions, (b) the evaporative efficiency of the same boiler under different conditions, and (c) the values of different fuels in the same boiler under the same conditions. To determine the evaporative efficiency, the boiler tests are generally made on shore before the boiler has been installed. They may be made on board ship with the boiler connected to the engines, in which case the engines are tested at the same time.

When a naval boiler is tested for any purpose, the code of rules given previously should be followed carefully in order that the results may be compared with similar tests of other boilers.

The object of the test is always to obtain reliable data, and no point that in any way bears on the test, no matter how insignificant it may seem, should fail to be accurately recorded.

All data should be carefully taken and accurately recorded.

Instruments should be calibrated and records be made both before and after a test. The thermometers should be graduated to read to one-tenth of a degree.

Every detail and every happening during the test should be accurately recorded, giving the time.

The apparatus used and the methods of operation are described in Appendix under the following heads, among others:

Hays' gas analysis.

Mahler's fuel calorimeter.

Pensky-Martens flash-point tester.

Methods and apparatus in testing liquid fuel.

Carpenter's throttling calorimeter.

Carpenter's improved separating calorimeter.

Barrus' draft gage.

Le Chatelier's pyrometer.

Ashcroft gage-testing set.

APPENDIX.*

STEAM CALORIMETERS, CORROSION INDICATORS, THERMOMETERS AND PYROMETERS, GAS ANALYSIS, FUEL CALORIMETERS, TESTS OF LIQUID FUEL, GAGE TESTING, SPECIFICATIONS, AND TABLES.

ACCESSORIES FOR MEASURING AND TESTING.

The following accessories are necessary to the efficient care and management of a boiler plant:

1. Steam calorimeters.
2. Chemical testing outfit.
3. Thermometers.
4. Pyrometers.
5. Gas-analysis outfit.
6. Fuel-testing outfit.
7. Liquid-fuel portable test outfit.
8. Gage-testing outfit.
9. Draft gage.
10. Smoke chart.

Steam Calorimeters.

Steam calorimeters are used for measuring the amount of moisture in the steam; from that measurement the quality is determined. There are three general classes in common use: (1) The *superheating* or *throttling;* (2) the *separating;* and (3) the *condensing* calorimeters.

One type of superheating and one of separating calorimeters will be described.

* By courteous permission of Commander U. T. Holmes, U. S. N., the cuts and descriptions of the throttling calorimeter and of both kinds of fuel-testing outfits were taken from Holmes' Experimental Engineering, 1911 edition. The descriptions have, in some cases, been slightly changed and shortened. The description of the proximate analysis of coal is also taken from Holmes.

Carpenter's Throttling Calorimeters.—Fig. 103 shows Prof. Carpenter's throttling calorimeter. It consists of a small vessel *A*, to which steam is supplied through a stop valve and converging nozzle *B*. The vessel contains in its center a very deep cup, into which a thermometer is inserted for determining the temperature of the steam in the calorimeter. A cock *C* connects to a mercury-filled manometer for measuring the pressure of the steam in the calorimeter. The exhaust steam is discharged from the lower part of the calorimeter and is permitted to escape freely.

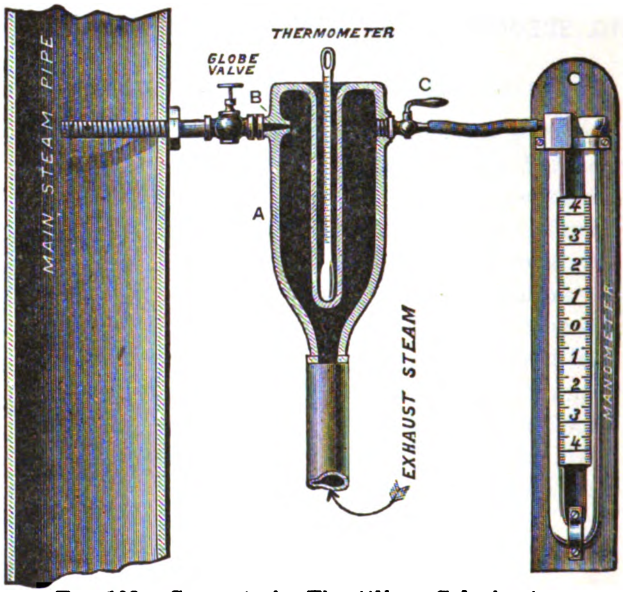


FIG. 103.—Carpenter's Throttling Calorimeter.

The principle of its operation follows from the superheating of steam when it is allowed to expand freely without doing work. The whole amount of heat in the steam must remain constant, but the total heat of vaporization being greater at a higher than at a lower pressure, the difference goes to superheat the steam of lower pressure. Let

p_1 = boiler pressure, absolute.
p_2 = pressure in calorimeter, absolute.
t_c = temperature in calorimeter.
L_1 and S_1 = latent heat and sensible heat corresponding to p_1.
H_2 and t_2 = total heat and temperature corresponding to p_2.
s = specific heat of steam.
x = quality of steam required.

The heat in a pound of steam flowing to the orifice will be

$$xL_1+S_1,$$

and the heat in a pound of steam in the calorimeter after passing through the orifice will be

$$H_2+s(t_c-t_2).$$

Assuming that no heat is lost or converted into work, these two expressions must be equal, from which

$$x=\frac{H_2+s(t_c-t_2)-S_1}{L_1}=\frac{H_2-S_1+s\ (t_c-t_2)}{L_1}. \qquad (1)$$

Specific heats of superheated steam is taken as .48; and H_2, S_1, L_1 and t_2 are found from the steam table. $1-x=$ the percentage of moisture in the steam.

In practical use of this instrument, it is customary to exhaust at atmospheric pressure, so that the normal temperature in the calorimeter is the boiling-point at atmospheric pressure. H_2 then becomes 1147 from the steam tables, and t_2 becomes 212.

Calibration Method.—The throttling calorimeter is frequently used to determine the quality of steam at a constant pressure, as in boiler tests. In such cases, if the discharge valve on the steam line is closed so that the only outlet is through the calorimeter, dry saturated steam will flow into it. Let T be the corresponding temperature in the calorimeter. Equation (1) then becomes

$$1=\frac{H_2+s(T-t_2)-S_1}{L_1}.$$

During the test, if t be the observed temperature in the calorimeter, the boiler pressure being the same as before, we have

$$x=\frac{H_2+s(t-t_2)-S_1}{L_1},$$

and the percentage of moisture equals

$$1-x=\frac{s(T-t)}{L_1}=\frac{.48(T-t)}{L_1}.$$

If x is greater than unity, the steam is superheated.

Limitations of Throttling Calorimeter.—If the percentage of moisture is so great that the steam, expanding into the calorimeter, does not become completely dried, the instrument is of no value. The theoretical limit is found for any initial temperature t_1 by putting $t_c=t_2$ in equation (1). The practical limit is somewhat lower, and varies from 2.3% of moisture at 50 pounds boiler pressure to about 7% at 300 pounds.

The range of the instrument can be increased by connecting the exhaust to a condenser. Thus, with a vacuum of 28″ and a steam

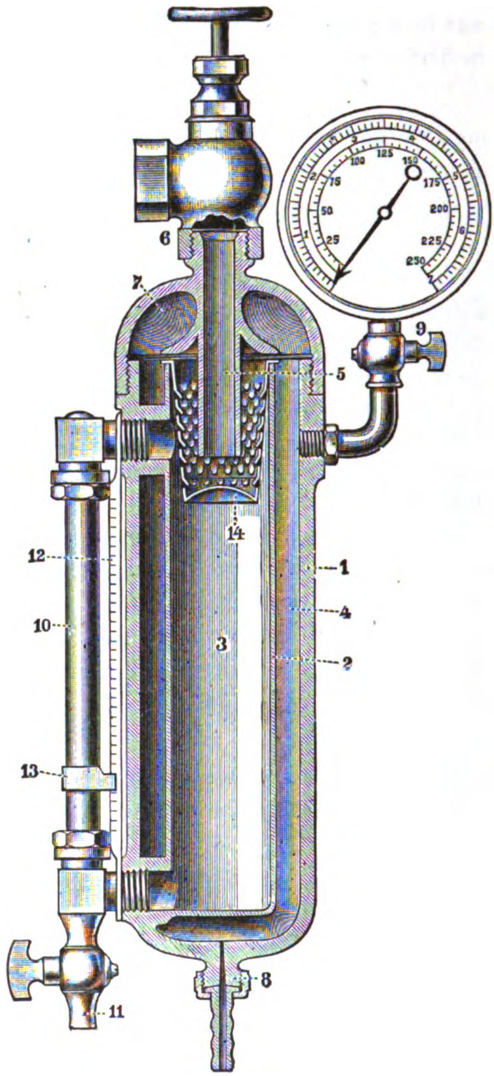


FIG. 104.—Carpenter's Improved Separating Calorimeter.

pressure of 50 pounds gage, the limit percentage of moisture would be about 8%.

For small percentages of moisture the throttling calorimeter is the handiest and most accurate form of apparatus. The sampling

nozzle of this instrument must extend almost across the steam pipes and have a sufficient number of small holes in it to insure its getting an average sample of the steam. To obtain reliable readings, the calorimeter should be thoroughly warmed up; and if readings are taken at frequent intervals, steam should be blown through continuously. The calorimeter and the connection to the steam pipe must be well lagged to prevent loss of heat by radiation.

Carpenter's improved separating calorimeter, shown in Fig. 104, contains two vessels, one inside the other. The outer surrounds the inner, leaving a space which serves as a steam jacket. The inner vessel is provided with a glass water gage 10 and scale 12.

The steam under test is admitted through pipe 6, striking the bottom of a perforated cup 14, and is deflected nearly 180°. The water is thrown off and passes through the perforations into the inner vessel 3, where the amount is indicated by the graduated scale 12 on the gage glass. The steam passes across the top of the perforated cup and into the outside chamber, from which it is discharged through a small orifice 8, of known area, in the bottom part. The orifice 8 is so small in comparison with any section of the steam pipe or throttle valve that there is no sensible reduction in pressure by passing through the calorimeter. The pressure in the outer chamber being the same as that in the inner, it has the same temperature, and consequently there is no loss by radiation from the interior surface except that which takes place from the exposed surface of the gage glass.

It has been demonstrated that the flow of steam through a small orifice is proportional to the absolute steam pressure, until the pressure against which the flow takes place equals or exceeds 0.6 of that in the vessel under pressure. A special form of steam gage is placed on the outer chamber, the inner circle of which shows the gage pressure, while the outer circle shows the number of pounds of steam that will escape through the orifice in 10 minutes of time.

The scale 12 is graduated to hundredths of a pound, and shows the weight of water contained in the inner vessel. The instrument is operated at a constant pressure for 10 minutes, and w, the weight of water collected, is read off; also W, the weight of dry steam that escapes through the orifice, is read off on the outer circle of the steam gage. Then

$$x = \frac{W}{W+w}, \text{ and } 1-x = \frac{w}{W+w}.$$

The separating calorimeter is accurate and applicable in all cases where the steam contains moisture. It is not applicable with superheated steam.

The sampling nozzle in the steam pipe must be fitted to get an average sample of the steam, and the instrument and its connections must be well lagged.

Corrosion Indicators.

The Action of Corrosion as Shown by Indicators.—Doctors Cushman and Walker have devised a means of showing the action of corrosion on iron and steel in what they call the *ferroxyl mount.* This mount is made as follows: A 1½% solution of agar-agar (a vegetable gelatine) in distilled water is boiled for an hour, and is then made rigidly neutral, *i. e.,* neither acid nor alkaline. While the solution is hot, a few drops of each of the indicators, ferricyanide of potassium and phenolphthalein, are poured into it. A thin film of this solution is poured over the bottom of a white dish and allowed to cool until stiff. The specimens of metal are placed on this film, and enough more of the hot solution is poured over them to cover them completely. The mount is then set away in a dark place and allowed to stiffen. When the solution cools, it forms a stiff, transparent jelly, in which the metal specimens are plainly visible. The mount can be kept almost indefinitely if a thin layer of alcohol is kept over its surface. Where the iron corrodes at its points of high solution tension, the ferricyanide combines with the iron ions, and forms a deep-blue compound known as *Turnbull's blue.* At points of low solution tension, where the hydrogen ion is giving up its charge, the hydroxyl ion (OH) combines with the phenolphthalein and forms a red compound. These colors appear very shortly after the mount is prepared. If the specimen of iron is pure and homogeneous as regards the states of stress of the molecules in its surfaces, there will be no color reactions and no corrosion.

When the mount is prepared properly and the color reactions develop, the difference of potential and current flowing from the blue areas to those of red can be measured by means of a properly fitted potentiometer.

If a specimen of pure iron is prepared in such a way that every point in its surface has the same solution tension, and is then placed alone in the mount, there will be no color reactions and no corrosion. If it is removed from the mount and connected by a metal wire to

another specimen of a metal of lower solution tension, prepared in the same way, and the two are then placed in a mount, the blue will develop all over the iron and the red all over the second specimen of lower tension. If the second specimen is of higher solution tension than the iron, and is prepared and connected as above, the red will develop all over the iron, and the color of the compound formed by the ions of the second metal with the ferricyanide will develop all over the second specimen. This color may not be blue. The colors in the mount showing that corrosion is taking place are not the same with all metals; with zinc the anode is white.

Practical Results from the Use of the Ferroxyl Mount.—A specimen of ordinarily good boiler plate steel prepared alone in this mount and preserved for some time will show red and blue all over its surface. On some days, areas that were red the day before will be blue, and *vice versa*. The colors will be shifting from time to time, with no permanent areas of color. This is due to the fact that there is very little difference between the solution tensions of the different points. The surface that is of high solution tension may have the cause for the high tension corroded away and a new surface exposed by tomorrow that has a lower tension than that of the lowest point of today. A plate that will give this reversible color reaction in the mount will corrode evenly all over if immersed in water. If the specimen, when developed in the mount, shows permanent blue and red areas over its surface, the metal has permanent points of high and low solution tension; and if subjected to the action of water for some length of time, deep pits will be found under the blue spots and the surface under the red will remain bright.

When iron is immersed in water, it corrodes in one of the two following ways: (1) Evenly all over the surface, *i. e.*, the areas of high and low solution tension vary from time to time; and (2) in spots on the surface, other adjacent spots remaining unaffected, *i. e.*, the areas of high and low solution tension are permanent. Corrosion in the second way is the most harmful form, and is known as *pitting*. When a plate, tube or pipe is pitting, it will last only the length of time that it takes the point of highest permanent solution tension to pit through, *i. e.*, its life is the life of the point that pits through the quickest; while if it is corroding evenly, it will last much longer.

Thermometers and Pyrometers.

Thermometers.—Ordinary glass mercurial thermometers are used for measuring temperatures of feed water, saturated steam and air when these temperatures are not higher than 500° F.

Thermometers are placed in so-called *thermometer wells,* which screw through the container casing and extend well into the current of gas or liquid to be measured. The bottom of the well should be filled with mercury or mineral oil of high boiling-point. The thermometer should be inserted into the well so that only a few degrees on the stem below the expected mean temperature should be visible. This obviates the necessity for a stem correction.

Stem Correction.—If the stem of the thermometer is not submerged to the height of the mercury, a stem correction must be made to compensate for the difference in expansion of the glass and the mercury.

A second thermometer is secured by pieces of string or wire to the one on which the readings are taken; and the bulb of the second thermometer is wrapped with waste, in order that it may show the temperature of the stem to which it is attached. The correction to be applied to the reading of the first thermometer is given by the formula:

$$\text{Stem correction} = .000088\, u(T-t),$$

where u = number of degrees projecting from liquid,

T = reading of immersed thermometer in degrees F.,

t = reading of auxiliary (second) thermometer in degrees F.

This correction is always positive.

Pyrometers.—For temperatures above 500° F., pyrometers must be used. These are of several forms, as (1) *pneumatic,* (2) *mercurial,* (3) *expansion,* (4) *calorimetric,* (5) *thermo-electric,* (6) *resistance,* and (7) *reflecting.*

Le Chatelier's Pyrometer.—This is a most reliable instrument for measuring high temperatures. It consists of a thermo-element composed of a platinum wire and another of an alloy of platinum and rhodium. The wires are insulated by a thin porcelain tube, and the junction is protected from the gases by a larger, closed porcelain tube. The current of electricity, generated by exposing the junction to heat, is measured by a suitable galvanometer, which has a carefully calibrated temperature scale besides the voltage scale. The junction of the thermo-couple is in the form of a small ball or button.

Fig. 106 shows an improved form of this instrument devised by the Vulcan Manufacturing Company, of Pittsburgh.* This form was designed for use in ascertaining the temperatures of molten metal, for which purpose the porcelain tubes would not answer. Even with the ordinary measurements of the gases of combustion, the porcelain tubes have to be handled with great care to prevent breaking.

An iron tube, through which run the wires of the couple, has a connection at one end for the clay tip which protects the junction, and, at the other end, a terminal box for the copper wire connections to the galvanometer. The wires are covered with asbestos for insulation from each other and from the iron pipe, and are covered by an asbestos tube where they pass through the fire-clay tip. The

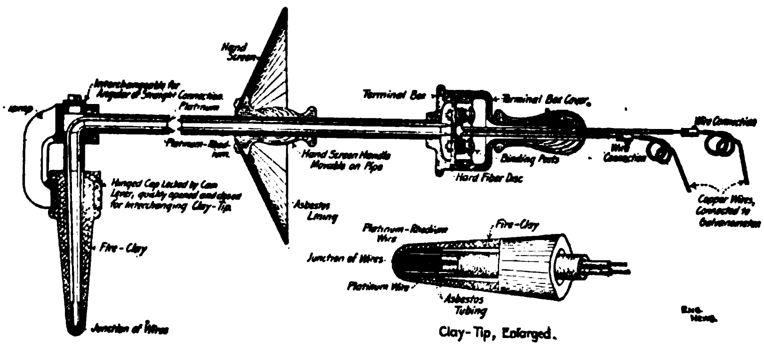


FIG. 106.—Le Chatelier's Pyrometer.

connection for this tip is interchangeable, so that the tip may be secured at an angle, as in the figure, or straight. The rest of the instrument is fully explained by the figure.

The galvanometer used is a D'Arsonval, specially made and calibrated for industrial purposes, the original form, with a reflecting mirror, and capable of registering to $\frac{1}{2}°$, being too cumbersome and delicate. The sensitiveness of the couple, even when protected by a refractory material, is such that, when it is plunged cold into the melted iron, the reading is obtained in $1\frac{3}{4}$ minutes. When it is heated to redness beforehand, this time is reduced to a few seconds.

An automatic recording device is sometimes added.

* From a paper on "The Melting Point of Cast Iron," by Dr. R. Moldenke, reprinted in the Journal of the American Society of Naval Engineers, Vol. X.

Gas-Analysis Outfits.

These outfits are constructed on the principle of measuring the volume of a gaseous mixture, treating it with a chemical that absorbs one of the constituents, and then, when the volume is remeasured, calculating the percentage volume of the absorbed constituent from the difference in the first and second volumetric measurements. The percentage volume of any absorbable gas constituent can be determined by use of the analysis outfits, but their principal use in the navy occurs in the analysis of the gases of combustion, carbon dioxide (CO_2), oxygen (O) and carbonic oxide (CO). The gases are drawn through sampling pipes from the furnace, from amongst the tubes or from the uptake. In collecting gas for examination, care must be taken that the sampling pipes reach to about the middle of the gas current, in order to get an average sample.

Several kinds of gas-analysis outfits have been used, among which are the Elliott, the Orsatt-Muencke and the Hays. The last-named is supplied to many vessels in the United States Navy, and its introduction has resulted in increased efficiency of firing, with consequent reduction in fuel consumption.

Hays Gas-Analysis Apparatus.—The Hays apparatus is shown in Fig. 107, and consists of the following essential parts:

1. The measuring burette *A'*.
2. The leveling bottle *C,* filled with water made slightly acid.
3. The absorption vessel *B.*
4. The vessel *F,* which holds the absorption liquid.
5. The aspirator *P* and its tubing.

There is, in addition, a funnel *E,* a beaker *I,* a collecting bottle *V* and numerous pinch-cocks to allow proper manipulation of the gases and fluids; all of these can be seen on the sketch.

To enter into a little more detailed description of the essential parts of the apparatus, the burette *A'* is graduated from zero to 21, the zero being near the bottom. *A'* is connected to the leveling bottle *C,* which is kept open to the atmosphere. When the leveling bottle is lowered and the proper cocks are opened, and the aspirator *P* is worked, gas will be pumped through the sampling pipe and *A'* will fill. If *C* is raised, with the cocks above and to right and left of *A'* closed, the water will rise toward the zero of *A'*. By opening slightly the pinch-cock on *U,* as *C* is raised, enough gas will be forced out of *A'* to allow the water level in *C* to come to the height

of the zero in A'. As C is open to the atmosphere, A' will then be filled down to the zero with gas under atmospheric pressure, a condition that must be fulfilled accurately before any test is started. In order to obtain this condition, the eye must be on the same level as the zero in A', and the water level in C must be brought to the same horizontal line while manipulating the pinch-cock in U. A'

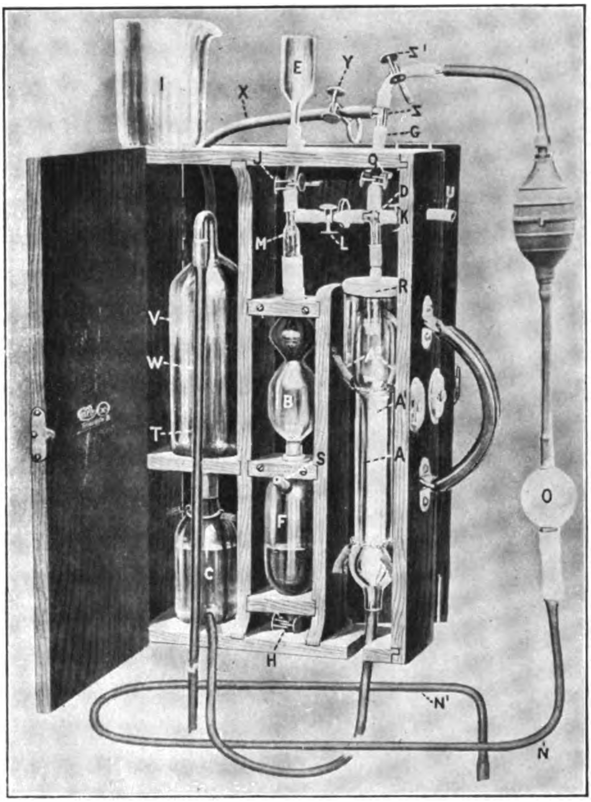


FIG. 107.—Hays Gas-Analysis Apparatus.

is surrounded by water in the space enclosed by A, to keep the gas at uniform temperature during the experiment. To avoid breakage, A is held in the center of its compartment by the springs A^2. As can be seen from the sketch, A' is connected at its top to the sampling pipe through P, and by tubing to B and V.

The vessel B is connected to A' by the tubing as shown; one branch goes up to the funnel E and one down to the vessel F. The

bulb of B up to M is filled with fine copper wire, which, when the absorbing liquid is forced down into F by the gas under treatment, exposes the gas to a large area of wet absorption surface. The vessel F is used to carry the absorbing liquid; it has an opening S near the top for filling, and a drain H at the bottom. F is filled to near the top with the absorbing liquid before any gas is drawn into A' for analysis. Then by raising C, with U open, the water can be made to rise, filling A'; by closing U and lowering C, the absorbing liquid will rise to M. This is the condition of the absorbing liquid at the beginning of an operation.

The analysis is, in brief, as follows: A sample of gas is drawn into A', filling it from zero to L. This gas is under atmospheric pressure, as the top of C is open, and the eye, the water in C and the zero are in same horizontal plane. By opening L and raising C until the water enters the bottom of the capillary tube at top of A', the gas is forced into the absorbing liquid in B.

It takes about 1 minute for the absorption of CO_2, and about 5 minutes each for O and CO. C is now lowered until the absorbing liquid comes back to M, and the measurement is read off on A'.

A' is graduated to read in percentage of volume. The reason for not graduating the burette to over 21% is that, in the principal use of this apparatus, analysis of gases of combustion, the sum of the percentage volumes of CO_2, O and CO never amounts to over 21% of the whole volume.

All readings should be made on the bottom of the meniscus, or curve of water, in the burette; it is essential to have C open, and to have the eye in the same horizontal plane with the water level in C and in A'.

Suppose, for instance, that the analysis was started with the gas mixture filling the space from zero to L. If, after the absorption of gas, the water in C and A' balances, say at 12, then 12% of the original volume was absorbed. If another constituent of the same gas is now absorbed and the second reading is, say, 16, then the second gas absorbed occupied $16-12$ or 4% of the original volume. Suppose a third constituent is now absorbed and the reading at completion of the absorption is 17.5, then the third constituent occupied $17.5-16=1.5$% of the original volume.

After making the determinations for one constituent of the gas mixture, drain B and F and wash them out well with distilled water before putting in the new absorbent solution. Some-

times it is convenient to make several CO_2 determinations before stopping to determine the percentages of O and CO. After each CO_2 absorption, pass the residue into *V* by opening *Y* and raising *C* until a composite sample is obtained, which can be used for analysis of CO and O. As each residue of gas is passed into *V*, part of the water will be displaced from *V* through the tube *T*. If a large number of tests have been made, *V* will not hold all the residues; so 5% of each residue may be taken. For example: The percentage of CO_2 is 12, the water standing at the 12 mark on the "second reading." This leaves a residue of 88. 5% of 88 is 4.4. Passing this quantity of gas into *V* would bring the water level in the burette up to 16.4. The leveling bottle should be used to make sure that the 16.4 reading is made under atmospheric pressure.

When through with the CO_2 analysis, compute the average of all of the determinations made. We will assume that it is 10%. Fill the beaker *I* with water, submerge the open end of *T* and draw gas from *V* into the burette. Level the gas on the 10% mark, expelling surplus gas through *U*. Now proceed with the oxygen absorption. The gas must be passed several times into the oxygen absorbent in *B*, measuring each time in *A'* until no more gas will be absorbed. Assuming that the level becomes stable at 19, the percentage of oxygen in the mixture is $19-10$ or 9. Now draw off the oxygen absorbent, being careful that *B* and *F* do not admit air, and proceed with the absorption of CO, using the proper absorbent.

As the CO absorption may result in generation of heat, water should be flowed into *B* to cool the gas before the final measurement is taken. At the end of the absorption of CO, read the burette. We assumed that the reading after the absorption of O was 19. If, after the CO is absorbed, the reading is, say, 19.5, the percentage of CO is $19.5-19$ or one-half of 1%.

In the analysis of gases of combustion, the constituents must be taken in the order CO_2, O and CO, as the absorption liquid for CO will take in solution some of the oxygen, and that for oxygen will take in solution some of the CO_2.

The absorbents are: (1) **For CO_2**, potassic hydrate, prepared by dissolving 1 part (by weight) of caustic potash (commercial stick form) in 2 parts distilled water (by weight); (2) **for free oxygen**, potassic pyrogallate, prepared by mixing together 5 grams pyrogallic acid in 15 cc. distilled water and 180 grams of caustic potash (commercial stick form) which has been dissolved in 80 cc. of dis-

tilled water; * (3) for CO, two absorbents are in use: (A) cuprous chloride solution in HCl, prepared by saturating distilled water with cuprous chloride and adding an equal volume of concentrated HCl, or †(B) ammoniacal cuprous chloride, prepared as follows: (x) 200 grams commercial cuprous chloride are shaken in a closed flask with a solution of ammonium chloride (250 grams ammonium chloride in 750 cc. distilled water); (y) to every three volumes of this mixture 1 volume of ammonia (sp. gr. .91) is added. (x) and (y) are kept separate, and are mixed when needed; if kept mixed, a clean copper wire must be kept in the bottle. The absorption values per cc. of the reagents are about: (1) 40 cc. of CO_2, (2) 22 cc. of O, (3A) 6 cc. of CO, and (3B) 16 cc. of CO.

Notes and Precautions in Regard to the Analysis.—In order to clear *A′* of air in preparation for a test, raise *C* with *U* open; the water will go up to the top of *A′*. Now lower *C*, close *U* and work the aspirator. Gas will be pumped through the burette, and will bubble out of the leveling bottle *C*. *P* must be worked until the operator is satisfied that all the air in the sampling pipe has been pumped through and a fair sample of gas is coming into the burette.

A book of detailed instruction is furnished with each apparatus.

From the fact that all boilers do not steam with equal efficiency at the same percentage of CO_2, and that CO_2 alone is not the absolute guide to maximum efficiency, it is believed that the best instrument for gas analysis is one in which the percentages of CO_2, CO and O in each sample can be quickly determined. The Hays instrument is satisfactory for use where only the CO_2 is to be measured. Where it is desired to measure the CO_2, O and CO in each sample, this instrument is cumbersome and requires much time.

Orsatt-Muencke Apparatus.—The Orsatt-Muencke apparatus, shown in Fig. 107a, is one in which the three reagents are carried in separate pipettes *A*, *A′* and *A″*. *B* is the graduated burette connected to leveling bottle *K* by a rubber hose, and surrounded by a water jacket. The reagents, instead of being put into one tube successively, are kept in separate treating pipettes, *A*, *A′*, *A″*. These are U-shaped, with one end of each connected by rubber tubing and a stop-cock to the pipe which supplies the gas to *B* from *F*.

* The oxygen should be measured at a temperature higher than 60° F Pyrogallic acid, a white powder, comes in a dark bottle or dark wrapper and is affected by light. The pyrogallate solution should be kept in a dark bottle, tightly stoppered.

† Used by Bureau of Mines.

The other ends of A' and A'' are connected to two siphon bottles, forming a water seal to prevent air from the atmosphere from getting to the reagents. These siphon bottles (not shown) and the other end of A are open to the atmosphere. To increase the absorbing surface of the reagents, the pipettes are filled with glass tubes. The reagents are the same as given under the Hays' apparatus above.

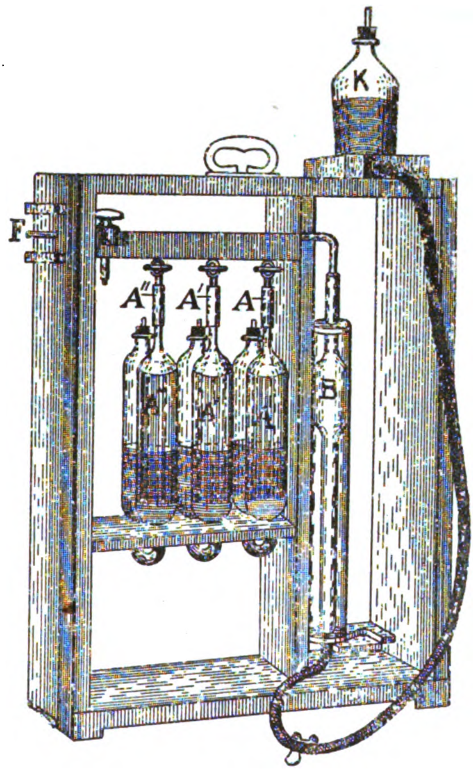


FIG. 107a.—Orsatt-Muencke Apparatus.

The order in which the gases are absorbed is the same, the reagent for CO_2 being in the pipette A nearest the measuring tube, that for O in A' and that for CO in A''.

In beginning an analysis, the reagents must be adjusted in the capillary tubes so that the level will be at a mark at the top of the pipette near the rubber connector. After the apparatus has been connected to the aspirator, and the leveling bottle has been filled with water, draw enough gas into the measuring tube to fill it, by

lowering the bottle and opening the top pipe to the aspirator connection. This gas is then discharged by raising the bottle, the apparatus and connections thus being cleared of air.

Now draw in 100 cc. of the gas, observing the same precautions in measuring as given above. Then open the cock on the first pipette, and allow the reagent in it to absorb the carbon dioxide, by running the gas in and out of the pipette about four times. At the last time, the reagent must be allowed to fill the leg next to the measuring tube up to the mark. A rubber bag is usually provided for the purpose of causing alternate suction and pressure in the open end of the pipette, and to keep the air from the reagent. In order to be sure that the absorption of CO_2 is complete, the test should be repeated until the last two readings agree within 0.1%. The same must be done with the tests for O and CO, except that in the last case the readings must agree exactly.

After the absorption of CO_2, and the return of the remaining volume of gas to the measuring tube, wait one minute before taking the reading, in order to let the water from the sides of the tube drain down. Owing to the water jacket on the measuring tube, two meniscuses will appear when looking at the scale. So long as the same meniscus is read for the whole analysis, no difference will be made. It is best to read the bottom of a meniscus always.

The operation is next repeated for the absorption of the O, and then for the CO, each requiring a longer time than the preceding one. The reduction in volume each time is, as before, the percentage of the particular gas in the mixture as drawn from the smoke-pipe, the remainder, after those gases have been absorbed, being classed as nitrogen. When transferring the gas during these operations, do not let the reagents, especially the caustic potash or pyrogallate, get into the measuring tube, as the water in the bottle must then be changed. Should a little water be allowed to get into the treating pipettes during a transfer, it will do no harm. About twenty minutes are required for an analysis by an expert with one apparatus. If two are used, two analyses may be made in twenty-five minutes.

Deductions from Results of Gas Analysis.—This analysis takes into account and measures the volumes of the dry gases. If the combustion were perfect and were accomplished with the exact amount of oxygen to provide for the chemical combination of the constituents of the fuel, the smoke-pipe gas analysis would show only

CO_2, and nitrogen (by difference). The H_2O or steam gas would not be measured.

To obtain perfect combustion of any fuel, it is required that excess oxygen above the theoretical amount be supplied; in practice, when combustion is as nearly perfect as possible, the analysis of the gases of combustion always shows CO_2, O and N.

When the percentage of O in the analysis is less than about 4, CO is found, indicating incomplete combustion due to insufficient excess of oxygen. This may be on account of the fires being too heavy, or the draft being too light, or both.

When the analysis shows over 8% of oxygen, it is found by practice that the excess of O is too great, on account of the fires being too light, or the draft being too heavy, or both, with a consequent loss of heat, due to the excess of air that has to be heated.

The presence of CO in the smoke-pipe gases indicates imperfect combustion and a consequent loss of heat. Each 1% of CO found indicates a loss of about 5% of the heating value of good steaming coal.

CO and O appearing together indicate that the air and combustible gases are not properly mixed, or that they are chilled below the ignition temperature by the heating surfaces of the boiler before they are completely burned.

A high percentage of CO_2, 4% to 8% O, and *any* CO indicates that the rate of combustion of that fuel in that boiler is too high and the combustible gases and oxygen are chilled before they are all burned.

High percentages of O and CO_2 in the same sample are never realized.

The percentage of N is found by taking $100-(CO_2+CO+O)$.

Where carbon is completely burned to CO_2, either with or without excess of air, the sum of CO_2 and O should equal 20.9%, and the N should equal 79.1%. (See composition of air.) Carbon burned to CO only, without excess of air, would give a gas containing 34.5% CO and 65.5% N. Hydrogen burned in the air without excess would give a gas 100% N.

If the sum of the percentages of CO_2, CO and O is less than 19, the analysis must be looked on with suspicion.

Calculations from the Results of Analyses.—One of the principal results derived from gas and coal analyses is the *heat balance,* which shows:

(A) The calorific value of the fuel (Dulong's formula, p. 329).

(B) The heat absorbed by the boiler.

(C) The loss due to the sensible heat in the smoke-pipe or waste gases.

(D) The loss due to latent heat in steam gases in smoke-pipe gases.

(E) Loss due to incomplete combustion.

(F) Other losses due to radiation and otherwise unaccounted for.

(A) **Calorific Value of the Fuel.**—Suppose the chemical analysis of a coal as fired gave, in per cent, 83.5 C, 4.8 H, 3.2 O, 1.2 N, 0.5 S, 1.5 moisture and 5.3 ash.

To reduce this to combustible * as a base, it must be remembered that the combustible portion of a coal as fired is 100% − (per cent of moisture + per cent of ash). The per cent of combustible in this coal will then be 100 − (1.5 + 5.3) = 93.2%. The percentages of C, H, O, N and S in the combustible will then be

$$83.5\times\frac{100}{93.2}=89.6\text{ C};\ 4.8\times\frac{100}{93.2}=5.15\text{ H};\ 3.2\times\frac{100}{93.2}=3.35\text{ O};$$

$$1.2\times\frac{100}{93.2}=1.29\text{ N};\text{ and }0.5\times\frac{100}{93.2}=0.545\text{ S}.$$

From Dulong's formula, which is heat units $=\frac{1}{100}[14{,}600\text{ C}+62{,}000(\text{H}-\frac{\text{O}}{8})]$, we get 16,015 as the calorific value per pound of combustible.

(B) **Heat Absorbed by the Boiler.**—This must be found from an evaporative test of a boiler; and let us suppose that in this case the number of pounds of water evaporated from and at 212° F. was 11.6 per pound of combustible. The heat absorbed by the boiler was then 11,257 = 11.6 × 970.4 (970.4 is the latent heat of steam at 212° F.).

(C) **Loss Due to Sensible Heat in Waste Gases** (per pound of combustible).—This is obtained from the analysis of the smoke-pipe gases and the ultimate analysis of the fuel (per pound of combustible).

There are two parts of this computation: (1) The calculation of the number of pounds of dry gas per pound of combustible, and (2) the calculation of the number of pounds of steam gas per pound of combustible from the per cent of H in the ultimate fuel analysis and from the per cent of moisture per pound of combustible.

* This is reduced to combustible as a base because the heat units are obtained from only the combustible constituents of the coal.

Calculation (1).—Let us assume that the analysis of the smoke-pipe gases gave, in per cent, 12.7 CO_2, 5.7 O, 0.5 CO, and 81.1 N (by difference). The per cent of N is found by taking $100-(CO_2+CO+O)$. The calculations of the heat lost in the smoke-pipe gas are based on the supposition that the dry gas contains only CO_2, CO, O and N. The gas may contain very slight amounts of H (decomposed from the moisture in the coal, probably just after firing), CH_4, (distilled from the coal and not burned), and SO_2 and NO_2 (from the sulphur and nitrogen in the coal). These last four gases are included in the per cent of N, as they are so small in amount that they may be neglected.

From chemistry it is learned that the weight of a gas is equal to its molecular weight, referred to hydrogen as unity. Each molecule of the gases H, O and N contains two atoms; their molecular weights are, therefore, twice their atomic weights.

Atomic weights: $O=16$, $H=1$, $C=12$, and $N=14$. The molecular weights of hydrogen and of the gases found from burning carbon in air are: $H=2$, $O=16$, $N=28$, $CO_2=12+32=44$, $CO=12+16=28$.

In CO_2 carbon forms (by weight) $\frac{12}{44}$, and oxygen $\frac{32}{44}$, or $\frac{3}{11}$ and $\frac{8}{11}$ respectively. In CO carbon forms $\frac{12}{28}$, and oxygen $\frac{16}{28}$, or $\frac{3}{7}$ and $\frac{4}{7}$ respectively.

The weight of the dry gases will then be the percentage (found by the analysis) of each gas multiplied by its molecular weight.

Pounds of dry gas $=\%CO_2\times 44+\%O\times 32+\%CO\times 28+\%N\times 28$. The pounds of dry gas per pound of carbon burned will be this number of pounds divided by the number of pounds of carbon in the gases containing carbon. The gases containing carbon are CO_2 and CO. The number of pounds of gases containing carbon will then be $\%CO_2\times 44+\%CO\times 28$, and the weight of carbon in these gases will then be

$$\tfrac{3}{11}\times\%CO_2\times 44+\tfrac{3}{7}\times\%CO\times 28=12(CO_2+CO),$$

as $\frac{3}{11}$ of CO_2 and $\frac{3}{7}$ of CO is carbon by weight. Letting the symbols represent the percentages by volume:

Pounds of dry gas per pound of carbon burned

$$=\frac{44CO_2+32O+28CO+28N}{12(CO_2+CO)}=\frac{11CO_2+8O+7(CO+N)}{3(CO_2+CO)}$$

Dry gas per pound of carbon

$$=\frac{11\times 12.7+8\times 5.7+7(0.5+81.1)}{3(12.7+0.5)}=19.1\text{ lbs.}$$

To reduce this to dry gas per pound of combustible, we must multiply it by $\frac{89.6}{100}$, or

Dry gas per pound of combustible $= 19.1 \times \frac{89.6}{100} = 17.1$ lbs.

Calculation (2).—In forming water, one part by weight of hydrogen combines with eight parts by weight of oxygen to form nine parts by weight of water. Therefore the weight of H per pound of combustible multiplied by 9 gives the weight of water formed per pound of combustible when it is burned. The steam gas per pound of combustible from the hydrogen would therefore be $.0515 \times 9 = .464$ lb. In addition there was 1.5% of moisture in the coal, and this forms $\frac{.015 \times 100}{93.2} = .016$ lb of steam gas per pound of combustible.

Summing up from calculations (1) and (2):

Dry gas per pound of combustible................	=	17.1 lbs.
Steam gas from H in fuel per pound of combustible..	=	.464 lb.
Steam gas from moisture in fuel per pound of combustible	=	.016 lb.
Total gas * per pound of combustible....		17.580 lbs.

Suppose the temperature of the gases in the uptake to be 590° F. and that of the external air 75° F. For all practical purposes, and in view of the approximate results which can be obtained by the present means of gas analysis, the average specific heat of the dry gases may be taken as .24, and of the dry gases and steam gases combined, as .246.

The rise in temperature of the gases is $590 - 75 = 515°$ F., and the product of the number of pounds of gases by the rise in temperature, in degrees F., by the specific heat of the gases equals the number of B. T. U. lost. 17.58 (lbs. of gases per lb. of combustible) $\times$ 515 (rise in temperature) $\times$ .246 (specific heat of gases) $= 2227.4$ B. T. U. lost, the loss due to the sensible heat in the waste gases per pound of combustible.

(D) **Loss Due to Latent Heat in Steam Gases.**—The loss due to the sensible heat has been accounted for in calculation (C). In addition, there is the loss of heat rendered latent in changing the water formed from the H and the moisture in the coal from water into steam. The latent heat of one pound of steam under atmos-

* This can be reduced to pounds of gas per pound of coal or per pound of carbon, if desired.

pheric pressure of 14.7 pounds per square inch is 970.4 B. T. U. As there was .48 pound of water formed per pound of combustible in the above example, this loss in B. T. U. is $970.4 \times .48 = 465.8$.

(E) **Loss Due to Incomplete Combustion.**—As found before, the weight of the carbon in the gases containing carbon was $12(CO_2 + CO)$. The perfect, or complete, combustion of this total carbon would have given $12(CO_2 + CO) \times 14{,}600$ B. T. U. = (a). But the combustion of the carbon, as shown by the gas analysis, was not complete, and the heat generated was, therefore, only

$$12CO_2 \times 14{,}600 + 12CO \times 4451\,^* \text{ B. T. U.} = (b).$$

The difference between (a) and (b) will give the loss in B. T. U. due to incomplete combustion of carbon, or loss $(a) - (b) = 12CO \times 10{,}149$ B. T. U. per pound of carbon, or, in per cent of (a)

$$= \frac{12CO \times 10{,}149 \times 100}{12(CO_2 + CO)} = \frac{CO \times 10{,}149 \times 100}{CO_2 + CO}$$

per lb. of carbon. Per pound of combustible this loss

$$= \frac{CO \times 10{,}149}{CO_2 + CO} \times \frac{\%C \text{ in combustible}}{100}.$$

Substituting values from the above gas analysis, we get loss due to incomplete combustion, per pound of combustible,

$$= \frac{.5 \times 10{,}149}{12.7 + .5} \times \frac{89.6}{100} = 344.4 \text{ B. T. U.}$$

(F) **Loss Due to Radiation and otherwise Unaccounted for.**—This is taken as the difference between (A), the calorific value of one pound of the combustible in B. T. U., and the sum of the values in (B), (C), (D) and (E) in B. T. U.

Heat Balance.—From the above calculations the *heat balance* is made up, which shows the approximate distribution of the heating value of one pound of the combustible.

HEAT BALANCE FROM THE ANALYSES GIVEN.

Calorific value of the combustible		16,015 B. T. U.
Absorbed by the boiler	11,257	
Loss due to sensible heat in waste gases	2,227.4	
Loss due to latent heat in steam gases	465.8	
Loss due to incomplete combustion	344.4	
Loss due to radiation and otherwise unaccounted for	1,720.4	
	16,015.0	

These values are frequently expressed in per cent of the calorific value of the combustible.

* See Table, chapter on "Combustion."

Tests of Coal, Proximate Analysis.

For Moisture.—A portion of the sample is accurately weighed into an oven and dried for 1 hour at a temperature of 105° F. The sample is then removed and reweighed. The difference gives the percentage of moisture.

For Volatile Matter.—A portion of the *dry* coal should be weighed into a flask and heated to incandescence for 15 minutes. This drives off the volatile combustible matter. The sample is then removed and reweighed; the difference, compared with the total weight of the original sample, gives the percentage of volatile matter.

For Ash.—The remainder of the sample, after the moisture and volatile matter have been driven off, is then weighed on a platinum dish, and then heated in the open air until all of the combustible matter is burned. The weight of the residue, compared with that of the original sample used, gives the percentage of ash. This is the net value of the ash, and is lower than it is possible to obtain in burning the coal on a grate. In practice, the ash is generally 50% greater than this.

The Fixed Carbon.—The fixed carbon is the difference between the weight of the original sample and the sum of the percentages of moisture, volatile matter and ash. It requires a chemist to make a chemical analysis of the fuel, in which the percentage of each of the constituents is obtained.

Sampling.—In sampling coal for a test, the object is to obtain a small portion of the coal which represents as nearly as possible the entire lot of coal under test. Small shovelfuls of the coal should be taken from many parts of the pile, car or barge, care being taken to get about the same number of shovelfuls from the top, middle and bottom of the pile. The sample should contain as nearly as possible the same percentages of lump and fine coal as exist in the whole pile under consideration. This sample is then broken up into small particles by crushing, or with a maul, and the whole is thoroughly mixed into a conical pile. The pile is then quartered. Two opposite quarters are then taken, the remaining two being rejected. The two taken are then mixed and quartered. This process is continued until the lumps are ¼″ in size or smaller, and a 1- or 2-quart sample remains. This sample is then hermetically sealed in glass or metal jars and plainly labeled. Before the jar is sealed, the identification record of the coal should be placed in the jar.

Fuel-Testing Outfit.

In obtaining the heating value of fuels, both solid and liquid, Mahler's fuel calorimeter is in very general use. This instrument is the best-known of the bomb calorimeters, in which a sample of the fuel under test is burned in a bomb immersed in water and the amount of the heat of combustion is measured by the rise in temperature of the water.

Principle, Description and Operation.—The combustible is placed in a closed bomb, made strong enough to resist heavy pressure and filled with oxygen under pressure. The bomb is immersed in the water of the calorimeter, and the combustion is started by an electric ignition device. Because of the large quantity of oxygen in the bomb, the combustible burns completely and almost instantaneously. The products of combustion are confined in the bomb, and the heat is given off to the water and to the various parts of the instrument. Such losses as occur are easily estimated, and, owing to the rapidity of the combustion, most of the corrections become negligible.

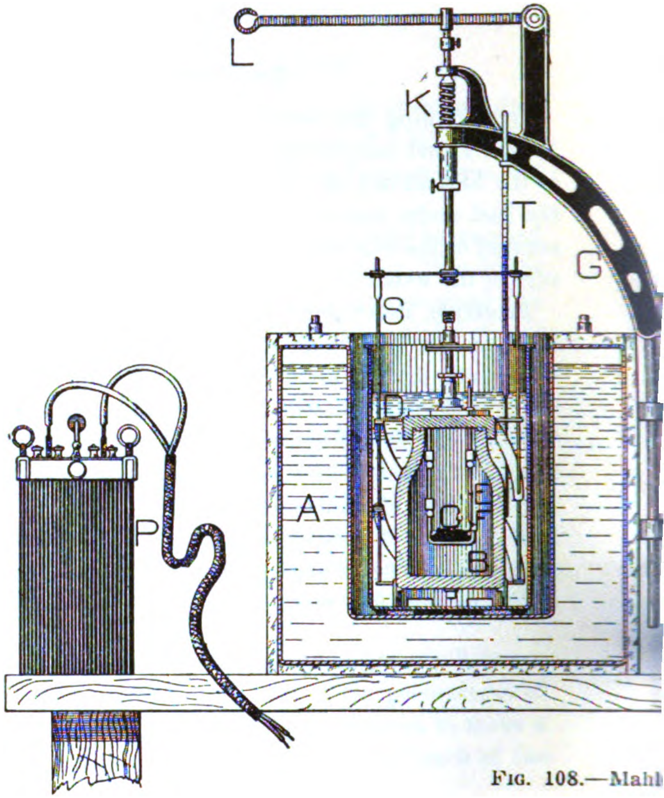
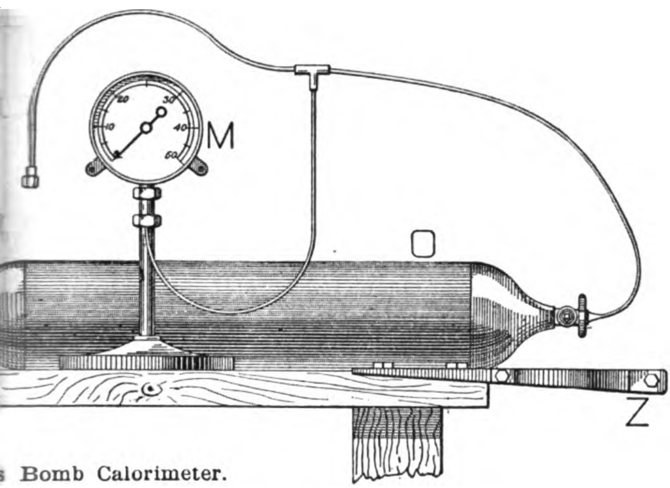


FIG. 108.—Mahl

The apparatus is shown in Fig. 108, and consists of the following parts: *A*, water jacket; *B*, bomb of enameled steel; *C*, platinum tray for holding the fuel; *D*, the calorimeter; *E*, an electrode; *F*, a piece of fine iron wire for priming; *G*, the support for the agitator; *K*, mechanism for agitator; *L*, the lever for operating; *M*, a pressure gage for oxygen; *O*, flask of oxygen; *P*, an electric battery; *S*, the agitator; *T*, a thermometer; and *Z*, a clamp for holding the bomb while removing or replacing the cap.

The bomb is of the best quality of forged steel, with walls 8 mm. in thickness and a capacity of about 650 cc. The capacity is such as to assure perfect combustion of the fuel by a considerable excess of oxygen. This bomb is used also for experiments with gas and gas mixtures.

The bomb is nickel-plated on the outside and enameled on the inside to protect it from attack by the nitric acid always formed during combustion. It is closed by a cap screwed down on a lead gasket. This cap has a valve in its center with a screwed nozzle for connecting to the oxygen flask, and is pierced by a well-insulated platinum electrode, which is prolonged on the inside by a platinum rod *E*. A second platinum rod, fixed to the cap, sustains the



... Bomb Calorimeter.

platinum tray *C*, which carries the sample of fuel under test. A spiral of very fine iron wire connects *C* with *E* and comes in contact with the fuel when the bomb is charged. When the current is turned on, this wire is heated to redness and then burns in the atmosphere of oxygen, igniting the fuel. The agitator, consisting of vanes, carried on a central rod with a spiral thread passing through a fixed nut, is operated by a lever, which permits the operator to stir the water in the calorimeter systematically, thus assuring an even temperature. The valve on the flask does not have a fine enough adjustment to permit the gradual introduction of the oxygen; hence, a second valve (not shown in the figure) having a very fine adjustment is placed in the connection to the tank for this purpose. The figure shows a flask for oxygen, containing about 1000 liters. It is ordinarily supplied in this manner at about 120 atmospheres pressure. Since the pressure convenient for the combustion of one gram of coal is only about 25 atmospheres, there is thus a provision for about 60 tests.

A high-grade thermometer, reading to $\frac{1}{50}$° C., an electric battery of 12 volts and 2 amperes capacity, and a stop watch, complete the apparatus.

The following method of procedure for determining the calorific value of a solid or liquid combustible is that given by the inventor of the apparatus: One gram of the fuel is weighed and placed in tray *C*. The small iron wire *F*, of known weight, is adjusted in contact with the fuel and serves as a primer. After putting the fuel and wire in the bomb, it is placed in the clamp *Z* and the cap is screwed on hard by means of a heavy hexagonal wrench. The valve on the cap is then opened, the second valve for fine adjustment (not shown) having first been closed. The valve on the flask is then opened, and then, very slowly, the adjusting valve, until the gage indicates 25 atmospheres. After having closed all valves, the tube is disconnected.

The bomb thus prepared is placed in the calorimeter *D*. The thermometer *T* and agitator *S* are placed in position, and a measured quantity of water, sufficient to cover the bomb completely, is poured in. This quantity will be about 2200 cc., which is the amount used by M. Mahler in his experiments. The water is stirred for some minutes, in order to let the whole system arrive at an even temperature; then observations are commenced.

The temperature is noted from minute to minute for 5 minutes, in order to fix the rate of variation of the thermometer before ignition. At the end of the fifth minute, contact is made and the fuel is fired by means of the battery connected to the electrode *E* and to a point on the valve. Ignition takes place immediately.

The temperature is noted half a minute after contact is made, and then at the end of a minute; and the observations are continued from minute to minute up to the point where the temperature begins to fall regularly. This, then, is the maximum temperature. The observations are then continued for five more minutes, in order to fix the variation of the thermometer after it reaches the maximum. The principal data for the calculations are then at hand, including data for the correction for loss of heat by radiation from the calorimeter. This correction is made according to the following rules, true between large limits, even where the amount of contained water is not more than half the water equivalent of the calorimeter:

1. The rate of decrease of temperature, observed after reaching the maximum, represents the loss of heat from the calorimeter before reaching the maximum, provided the fall in temperature is not greater than 1° C. per minute.

2. If the fall in temperature per minute is greater than 1°, but

less than 2° C., the figure representing the rate of decrease, when diminished by 0.05, gives the desired correction.

The two preceding paragraphs cover all cases. It is possible also, and that without altering the accuracy of the experiment, to consider the variation during the first half of the minute following the ignition as that which exists at the minimum temperature.

During the whole of the experiment the observer should continually operate the agitator. When the observations are ended, the valve on the bomb is first opened, then the bomb itself. The bomb will contain the ordinary products of combustion, composed principally of carbonic acid gas and water, a considerable quantity of free oxygen, and an appreciable quantity of nitric acid formed during the combustion from such nitrogen as was present in the bomb at atmospheric pressure before it was charged with oxygen.

The interior of the bomb is washed with a small quantity of water to remove the liquid acid formed during the combustion. The amount of nitric acid is then determined by a simple chemical analysis, and the calorific value h is determined from the formula:

$$h = r(1+a)(P+P') - (230p+1600p'),$$

where r = the rise in temperature.
a = the loss of temperature during the experiment.
P = the weight of water in the calorimeter.
P' = the water equivalent of the calorimeter.
p = the weight of nitric acid.
p' = the weight of the iron ignition wire.
230 = the heat of formation of 1 gram of nitric acid.
1600 = the heat of combustion of 1 gram of iron.

In making a test of coal, no separate account is taken of the quantity of sulphuric acid resulting from the oxidation of the small quantity of sulphur present in the sample, such acid being treated as nitric acid. The error is negligible in ordinary work. It may be noted that the sulphur being entirely oxidized and transformed into sulphuric acid, the bomb gives a means of evaluating it. For this purpose, in order to give a sufficient quantity for satisfactory operation, it will be better to burn 2 grams under 30 atmospheres, without taking readings of the thermometer. If desired, account may be taken of the heat generated by the formation of sulphuric acid, which is 0.73 calorie per gram of acid.

In testing a substance containing but little hydrogen, coke for

example, so little water of combustion is formed that the quantity is insufficient to dissolve the acid. It is then best to place in the bottom of the bomb a few cubic centimeters of water, which must be taken into account in making the calculations.

The procedure is the same for a liquid as for a solid. If the liquid gives off vapors, it is well to weigh the sample in a closed vial having thin points through which is passed the film of iron wire. At the moment of introducing the vial into the bomb, care should be taken to break these points in order to bring the oxygen into contact with the liquid.

This apparatus has also been used for the determination of the calorific value of various gases. After having exhausted the bomb and measured the pressure remaining, the gas is introduced for the first time. The bomb is then exhausted the second time, after which it is filled with the gas at atmospheric pressure, and at the temperature of the laboratory. The oxygen is then added and the procedure is carried on in the same manner as for solid and liquid fuels.

The determination of the calorific value of gases offers a special difficulty. If diluted with too great a quantity of oxygen, the mixture will not be combustible. Five atmospheres are sufficient for illuminating gas and one-half an atmosphere for producer gas, measured on a mercurial manometer.

Determination of the Water Equivalent of the System.—In order to determine the value of P', the term representing in water the exact equivalent of the system, the simplest method is to perform a double experiment as follows:

Burn in the bomb a known weight, 1 gram for example, of a combustible of fixed composition, such as fuel oil, and with 2300 grams of water in the calorimeter. Then burn the same weight of the same combustible with only 2100 grams of water in the calorimeter. There will then be two equations between which the heat of combustion of the fuel may be eliminated and the value of the water equivalent may be reduced.

Example.—The following example of the work of the apparatus is given by M. Mahler. The fuel under test is a sample of colza oil; an approximate analysis gave: Carbon, 77.182; hydrogen, 11.711; oxygen and nitrogen, 11.107; weight of sample tested, 1 gram; water in calorimeter, 2200 grams; water equivalent of the bomb and accessories, previously determined, 481 grams.

The apparatus being prepared, as above directed, a little time is allowed to elapse for the temperature to equalize; then the stop watch is started and the temperatures are noted as below.

PRELIMINARY PERIOD.

0 minutes	10.23°
1 minute	10.23
2 minutes	10.24
3 minutes	10.24
4 minutes	10.25
5 minutes	10.25

$$r_0 = \frac{10.25° - 10.23°}{5} = 0.004°$$

The combustible is then fired.

PERIOD OF COMBUSTION.

5½ minutes	10.80°
6 minutes	12.90
7 minutes	13.79
8 minutes	13.84 (max.)

FINAL PERIOD.

9 minutes	13.82°
10 minutes	13.81
11 minutes	13.80
12 minutes	13.79
13 minutes	13.78

$$r_t = \frac{13.84° - 13.78°}{5} = 0.012°$$

No further readings of the thermometer are taken.

The change in temperature has been $13.84° - 10.25° = 3.59°$.

Corrections.—The apparatus has lost, during the minutes (7, 8), (6, 7), a quantity of heat measured by $\frac{13.84° - 13.78°}{5} \times 2 = .024°$.

During the half minute ($5\frac{1}{2}$, 6) it has lost a quantity of heat represented by $(0.012° - 0.005°) \times \frac{1}{2} = 0.0035°$; and during the half minute (5, $5\frac{1}{2}$) it gained $\frac{10.25° - 10.23°}{5} \times \frac{1}{2} = .004° \times \frac{1}{2} = .002°$.

Finally, the loss during the minute (5, 6) is $0.0035° - 0.002° = 0.0015°$.

To sum up, the loss during the whole experiment has been $0.024° + 0.0015° = 0.0255°$, a quantity which should be added to the

3.59° already found. The corrected rise in temperature is then 3.615°, neglecting the ten-thousandths.

The quantity of heat observed is, therefore, $(2200+481) \times 3.615° = 9691.8$ calories.

In order to obtain the final result, we subtract from this figure:

1. The heat of formation of 0.13 gram of nitric acid, determined volumetrically, $0.13 \times 230 = 29.9$ calories.

2. The heat of combustion of 0.025 gram of iron wire, $0.025 \times 1600 = 40$ calories.

Amount to be deducted, 69.9 calories.

The final result is then $9691.8 - 69.9 = 9621.9$ calories, or, for a kilogram of oil, 9621.9 kilo-calories.

To transform this result into B. T. U. per pound, multiply by 1.8: $9621.9 \times 1.8 = 17{,}319.42$ B. T. U.

Applying the formula $h = 14{,}500[C + 4.28(H - \frac{O}{8})]$, we obtain for h the theoretical value 17,597.

Liquid-Fuel Portable Test Outfit.

A liquid-fuel portable test outfit that is furnished to all vessels that burn oil, and to all oil-supply stations, is shown in Fig. 109. The apparatus at the right of Fig. 109 is the Pensky-Martens flash tester, which is shown in detail in Fig. 110.

This outfit has instruments for determining the flash point, percentage of water and sediment, and specific gravity of liquid fuel. Samples are sent to the chemical laboratories at navy yards at Norfolk and Washington for the determination of the percentage of sulphur and the heating value.

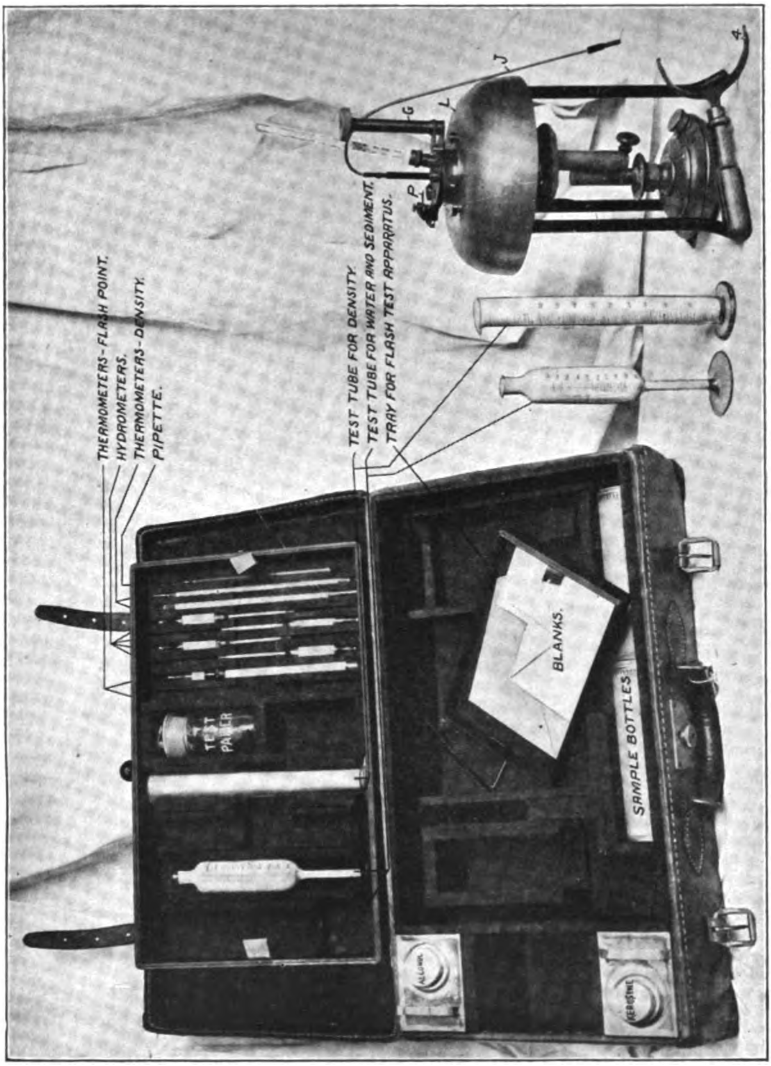


FIG. 109.—Liquid-Fuel Portable Test Outfit.

Pensky-Martens Flash Tester.—The Pensky-Martens apparatus for flash-point determination is shown in Fig. 110.

E is the oil container, which is placed in a metal heating vessel *H*, provided with a mantle *L*, in order to protect *H* from loss of heat by radiation. The oil cup *E* is closed by a tightly fitting lid, shown in plan 2. Through the center of the lid passes a shaft carrying

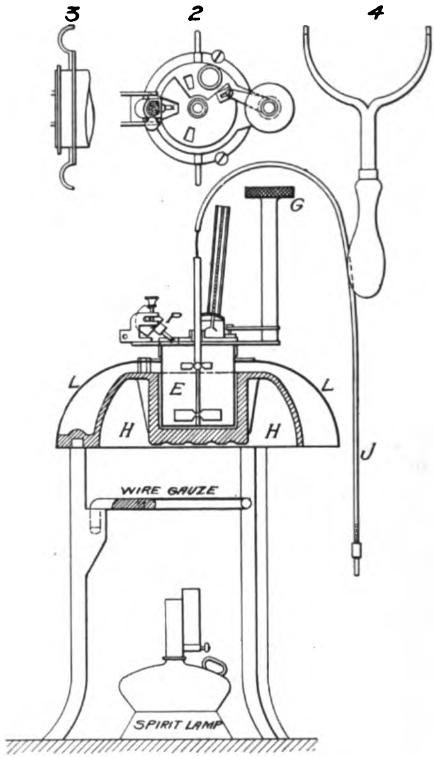


FIG. 110.—The Pensky-Martens Flash Tester.

the stirring arrangement, which is worked through a flexible connection by means of the handle *J*. In another opening of the cover is fixed a thermometer. The lid is perforated with several orifices, which are left open or covered, as the case may be, by a sliding cover. This can be rotated by turning the vertical spindle with milled head *G*. By turning *G*, an opening of the slide can be made to coincide with an orifice in the cover, and simultaneously a jet of flame *P*, from a very small spirit lamp, is tilted on the surface of the oil. This contrivance is shown better in plan 2.

Operation.—All water which is contained in the oil must be removed before testing for flash point, by filtering it through one of the small felt filters and funnels contained in the outfit. When the sample is prepared for test, the oil cup is filled up to the mark, the cover is fixed, and the oil is heated rapidly until its temperature reaches a point about 50° F. below the expected flash point. The wire-gauze screen shown in the figure is then placed in position, and the rate of rise in temperature is thus reduced to about 5° F. per minute. Handle *J* is turned slowly and continuously for stirring. From time to time the milled head *G* is turned, opening the shutter at the top of the cup and tilting the flame *P* into it. This is done at 5° F. rise in temperature until near the probable flash point when the intervals are made 2° F. When the flash point is reached, there will be a slight explosion when the flame is tilted down.

A sample can be used for only one test, since the more volatile products are given off and a subsequent test would show a higher flash point.

The Fire Test.—This is the temperature at which the oil will give off vapors which, when ignited, will burn continuously. It is made by continuing to heat the oil after the flash point has been determined. In this apparatus the cover is removed after the flash point has been determined; the thermometer is left in place. When the fire test is completed, the flame is extinguished by replacing the cover.

Test for Determining Water and Sediment.—The outfit contains a graduated glass cylinder, as shown in Fig. 109, having a small stem at the bottom, of 3 cc. capacity. Fifty cubic centimeters of the oil under test is placed in the cylinder, and an equal quantity of gasoline or kerosene is added. The whole is then shaken thoroughly and allowed to stand for at least 2 hours. All of the water and sediment will then be found to have settled in the narrow stem, where it can be measured. If bubbles are found to be adhering to the glass, they are removed with a thin wire agitator. Each cubic centimeter of water and sediment found in the stem will represent 2% in the sample tested.

Specific Gravity.—A sample of the oil is placed in the graduated glass jar, Fig. 109, and a hydrometer is slowly sunk into it. Care must be taken not to plunge the hydrometer deeper than it will float, as this will make an accurate reading impossible. After

reading the hydrometer, it is removed and the temperature is taken. By means of a correction table, the specific gravity is reduced to 60° F., which is the standard for comparison.

Commercially, the specific gravity of an oil in the United States is usually given according to the Baumé scale, an arbitrary standard whose value at various points is as follows, the weight per gallon being given at 60° F.:

10°	Baumé	=	specific gravity	1.000	=	8.331	pounds per gallon.
15	"	=	"	.967	=	8.056	"
20	"	=	"	.936	=	7.798	"
25	"	=	"	.907	=	7.556	"
30	"	=	"	.880	=	7.331	"
35	"	=	"	.854	=	7.115	"
40	"	=	"	.830	=	6.915	"
45	"	=	"	.807	=	6.723	"
50	"	=	"	.785	=	6.540	"
55	"	=	"	.765	=	6.373	"
60	"	=	"	.745	=	6.206	"

Gage-Testing Apparatus.

There are two kinds of testing outfits supplied, one of which, made by the Ashcroft Manufacturing Company, is shown in Fig. 111. The cylinder in the middle is a screw pump, the plunger of which is worked by the hand wheel, and which is connected by a pipe to the two cocks at the ends of the base. A standard test gage, the dial of which is graduated to single pounds, is screwed onto one of these cocks, and the gage to be tested is screwed onto the other. The hand wheel being run out, the pump cylinder and connecting pipes are filled with water through one of the cocks, and the gage is then screwed into place. Pressure is now applied by screwing in the hand wheel, the readings of the gage for every 5 pounds being compared with the test gage, from zero (or from the stop pin, which, in high-pressure gages, is set a few pounds above zero) to the working pressure and back again. If the difference between the two gages is constant, the pointer can be removed by the lifter provided and be set in the correct position. A gradually increasing or decreasing difference may be corrected by a slight change in the position of the slotted lever. In a modification of this apparatus, the screw pump is replaced by a lever pump.

In the second kind of testing outfit, the pressure is produced by weights, and is communicated directly to the gage to be tested. No

test gage and pump are needed. There is a pipe, turned up at the ends, secured in a base and fitted at one end with a cock for a gage, similar to Fig. 111. At the other end, there is an open cylinder in which a snug-fitting plunger, exactly 1 square inch in area, can move up and down easily. The top of this plunger

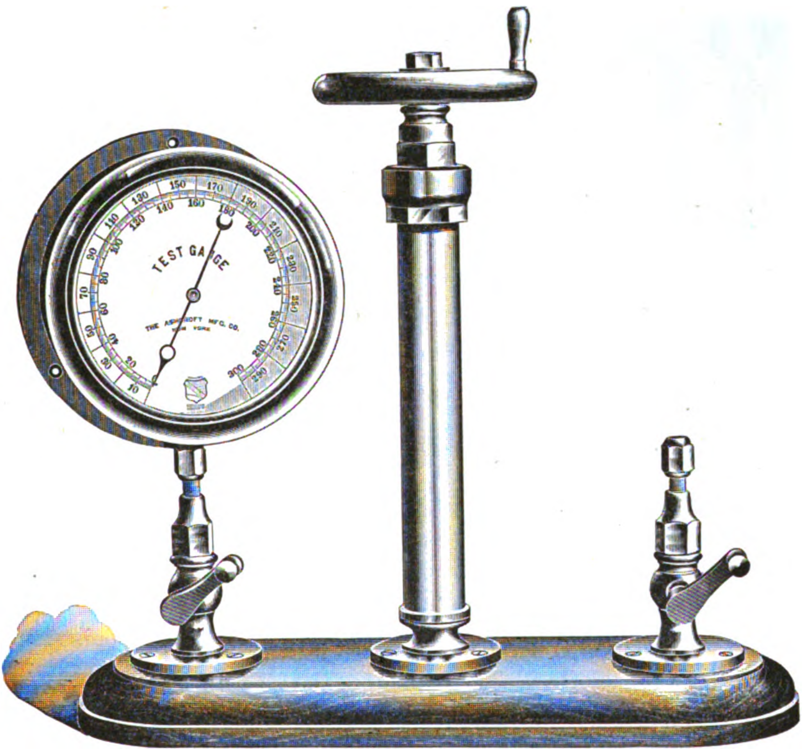


FIG. 111.—Gage-Testing Apparatus.

is fitted with a tray on which the weights are piled, thereby increasing the pressure per square inch as desired. Glycerine is generally used in this apparatus, instead of water, as it lubricates the cylinder. While testing a gage, the plunger and its weights should be rotated at intervals to insure its working with the least friction.

Draft Gage.

Barrus Draft Gage.—The ordinary air-pressure or draft gage lacks sensitiveness when measuring small quantities. The Barrus gage, Fig. 112, multiplies the indication of the ordinary U-tube by the use of two liquids of slightly different specific gravities, such as alcohol (colored red for ready observation) and a certain grade of petroleum oil.

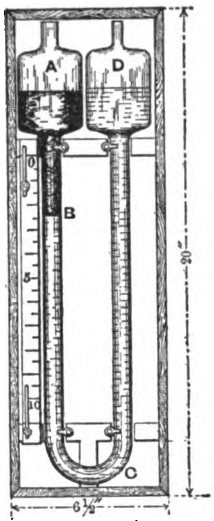


FIG. 112.—Barrus Draft Gage.

This instrument consists of a tube, usually made of ½" glass, which is surmounted by two glass chambers having a diameter of about 2½", and arranged as shown.

It is placed in a wooden case provided with a cover, and is secured in an upright position. Of the two liquids, which will not mix and which are of different colors, one occupies the portion *A-B,* and the other, which is the heavier, the portion *B-C-D.* When the right-hand tube is connected to the uptake or smoke-pipe, the suction produced by the draft draws the line of demarkation *B* downward. The amount of this motion is proportional to the difference in the areas of the two chambers of the U-tube, modified somewhat by the difference in the specific gravities of the liquids. By referring to the scale on the side, the amount of motion is measured in inches. This scale is movable, and can be adjusted to the zero point by loosening the thumb-screws. A multiplication varying from 8 to 10 times is obtained in the instrument shown; in other words, with ¼" of draft, the movement of the line of demarkation is from 2" to 2½", the exact amount of multiplication having been determined by calibration referred to a standard instrument.

Smoke Chart.

Smoke Observations.—In order to have a uniform system of determining and recording the density of smoke produced, the smoke chart invented by Prof. Ringlemann is now used. There are six cards, four ruled into small squares by lines of varying thickness, one entirely white, and another solid black. They are numbered from 0 to 5, and are hung in a horizontal row about 50

feet from the observer and, as nearly as is convenient, in line with the top of the smoke-pipe. At this distance, the lines on the ruled cards are not visible, and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances from the smoke to the cards and determines which one is nearest in color to that of the smoke. The number of the card and the time are then recorded. The observations should be frequent. The whole number of observations may then be plotted on cross-section paper, to show the variation in the smoke from time to time; and the average of all the records is taken as the average density for the test.

The ruled cards have usually 17 horizontal and 10 vertical lines, spaced 10 mm. apart between centers. The thickness of the lines is 1, 2.3, 3.7 and 5.5 mm. for cards Nos. 2, 3, 4 and 5, respectively, the white spaces left between the lines decreasing, therefore, from 9 to 4.5 mm. square.

SPECIFICATIONS.

Specifications for Boiler Fittings.—All external fittings on boilers will be composition G or Class B cast steel, as directed.

Each boiler will have the following fittings of approved design, with the necessary pipes and fittings for attaching same to boiler:

One steam stop valve closing toward the boiler.

One dry pipe in the steam drum or equivalent arrangement for insuring dry steam.

Two main-feed stop valves and two check valves, with internal pipe extending nearly the full length of the drum.

One auxiliary-feed stop valve and check valve, with internal pipe.

One surface blow valve, with internal pipe and scum pan.

One or more bottom blow valves, with internal pipes, or as may be directed.

One safety valve.

One steam gage.

Three gage cocks of U. S. Navy standard design, arranged to operate into the fire-room floor.

Two water gages with automatic fittings.

One air cock.

One stop valve ¾" in diameter, for cleaning pipe connections.

One connection for testing water.

* Zinc protectors, with baskets for catching pieces of disintegrating zinc.

* Use abandoned.

Polished-brass pressure and number plates, secured to the fronts of the boilers and to each burner.

Efficient and approved means for blowing soot off the tubes.

Baffle plates and deposit pans in the steam drum.

The number of fittings, as specified above, is for a boiler with a single steam drum. For a boiler with more than one steam drum the number of fittings may be correspondingly increased.

All external fittings on boilers will be flanged and through-bolted or attached in other approved manner.

All cocks, valves and pipes, unless fitted on pads or in other approved manner, will have spigots or nipples passing through the boiler plates.

All internal pipes will be of steel, 0.083″ thick, and will not touch the plates anywhere, except where they connect with their external fittings. The internal feed and blow pipes will be expanded in the holes in boiler drums to fit the nipples on their valves, or will be secured in other approved manner, and will be supported where necessary and as directed.

The design of internal feed pipes will depend upon the type of boiler adopted, and will be as approved.

All fire brick must be of standard size, attached by an approved method.

Boiler Spares.—The following spare parts will be furnished and carried on board:

Parts.	Quantity to be furnished.
Oil-fuel burners, complete	20 per cent.
Casing for oil-fuel burners, with doors	do.
Manhole plates, with bolts, nuts, and dogs	Complete for 2 boilers.
Gage cocks	do.
Water gages, complete	do.
Water-gage glasses	100 per cent.
Mica protecting shields for water-gage glasses	200 per cent.
Feed check valves	2 to each hand.
Surface blow valves	1 to each hand.
Bottom blow valves	do.
Handhole plates, including superheater, if fitted with bolts, nuts, and dogs	5 per cent of all.
Special fire brick	10 per cent of all.
Special fittings	As may be directed.
All tubes of each size and shape, including side and cross boxes and superheater, if fitted	5 per cent.
Springs for boiler safety valves	Complete for 1 boiler.

Specifications for Fuel Oil.—(a) Fuel oil shall be a hydrocarbon oil of best quality, free from grit, acid, and fibrous and other foreign matter likely to clog or injure the burners or valves.

(b) The unit of quantity to be the barrel of 42 gallons of 231 cubic inches at a standard temperature of 60° F. For every variation of temperature of 10° F. from the standard, 0.4 of 1% shall be added or deducted from the measured or gaged quantity for correction.

(c) Flash point never under 150° F. as a minimum (Abel or Pensky-Martens closed cup), or 175° F. (Tagliabue open cup), and not lower than the temperature at which the oil has a viscosity of 8 Engler (water = 1 Engler). Example: If an oil has a viscosity of 8 Engler when heated to 186° F., then 186° F. is the minimum flash point at which this oil will be accepted.

(d) Viscosity at 100° F. not greater than 200 Engler.

(e) Water and sediment not over 1%. If in excess of 1%, the excess to be subtracted from the volume; or the oil may be rejected.

Methods of Test.—(a) Flash point will be taken as indicated in the specifications.

(b) Viscosity will be taken by the Engler viscosimeter:

(c) Water and sediment will be taken by the distillation method. When oil in small lots is consigned to naval vessels or to navy yards, the centrifuge test will be used in order to obviate delay. In this test 50 cc. of oil and an equal quantity of best commercial benzol, 50% white, will be used, and the mixture will be heated to 100° F.

Determination of Quantity Delivered.—(a) The officer making the purchase shall, when not impracticable, have an agreement with the agent of the company, before delivery is made, as to the method of determining the quantity delivered. Measurements should be made, when possible, by representatives of the Government and the contractor acting jointly.

(b) When the oil is delivered in tank cars, where the tank cars are completely filled and completely discharged, the capacity to be taken from the gage table published under authority of the Interstate Commerce Commission, the quantity to be corrected for temperature.

(c) If cars are not completely filled or discharged, the quantity to be determined, if practicable, by weight at place of delivery. The unit of quantity to be the barrel of 42 gallons of 231 cubic inches at standard temperature of 60° F., the number of pounds per gallon

to be determined by the specific gravity of the oil at 60° F., multiplied by 8.3316 pounds, the weight of 1 gallon of distilled water at the same temperature.

(d) If determination of weight is not possible, the quantity is to be determined by the percentage of oil in the tank cars as determined by gage to the full capacity. Unsuitable oil at the bottom of a tank car, due to deposits, will not be accepted, and will be deducted from the total; otherwise the cars will be completely discharged.

(e) Where oil is delivered in barges to naval tanks, the quantity is to be determined by the tank's gage, allowing for capacity of lines.

(f) When oil is delivered in barges to naval vessels and the entire lot is discharged into the naval vessel, the quantities are to be determined by the reading of the gages of the shore tanks before and after the loading of the barges, as ascertained by the representatives of the contractor and of the Government.

(g) When oil taken from distant tanks is delivered to a naval vessel by barge, or the barge load is not entirely discharged into the vessel, the quantity is to be determined by the calibration of the ship's tanks, unless other method is previously agreed upon.

General Instructions.—(a) Fuel oil for use afloat shall be required for on requisition on the general storekeeper of the yard, and orders placed by him with the contractor in the same manner as for coal and other supplies.

(b) The greatest care possible must be taken to determine that all fuel oil for use afloat shall conform in every respect to the specifications before being taken aboard.

(c) For the purpose of making tests aboard ship, the Bureau of Steam Engineering will furnish, upon application, fuel-oil testing outfits for determining flash test, gravity test, cold test, and water test.

(d) Arrangements for supplying fuel oil to all naval fuel-oil storage tanks will be made by the bureau. General storekeepers concerned will keep the bureau advised of their requirements from time to time.

(e) *Caution.*—**Vouchers for payment should be prepared by the officer placing the order with the contractor, except orders placed by the bureau, when the vouchers should be prepared by the general storekeeper receiving the oil.**

TABLE I.

PROPERTIES OF SATURATED STEAM.

BRITISH UNITS.

Pressure in pounds per square inch, absolute.	Temperature of boiling point, degrees Fahr.	Sensible heat of the liquid, above 32° Fahr.	Total heat of steam, above 32° Fahr.	Latent heat of evaporation.	Specific volume, cubic feet per pound.	Density, pounds per cubic foot.
p.	t.	h.	H.	L.	v.	$1/v$.
1	101.83	69.8	1104.4	1034.6	333.0	0.00300
5	162.28	130.1	1130.5	1000.3	73.33	0.01364
10	193.22	161.1	1143.1	982.0	38.38	0.02606
14.7	212.0	180.0	1150.4	970.4	26.79	0.03732
15	213.0	181.0	1150.7	969.7	26.27	0.03806
20	228.0	196.1	1156.2	960.0	20.08	0.04980
25	240.1	208.4	1160.4	952.0	16.30	0.0614
30	250.3	218.8	1163.9	945.1	13.74	0.0728
35	259.3	227.9	1166.8	938.9	11.89	0.0841
40	267.3	236.1	1169.4	933.3	10.49	0.0953
45	274.5	243.4	1171.6	928.2	9.39	0.1065
50	281.0	250.1	1173.6	923.5	8.51	0.1175
55	287.1	256.3	1175.4	919.0	7.78	0.1285
60	292.7	262.1	1177.0	914.9	7.17	0.1394
65	298.0	267.5	1178.5	911.0	6.65	0.1503
70	302.9	272.6	1179.8	907.2	6.20	0.1612
75	307.6	277.4	1181.1	903.7	5.81	0.1721
80	312.0	282.0	1182.3	900.3	5.47	0.1829
85	316.3	286.3	1183.4	897.1	5.16	0.1937
90	320.3	290.5	1184.4	893.9	4.89	0.2044
95	324.1	294.5	1185.4	890.9	4.65	0.2151
100	327.8	298.3	1186.3	880.0	4.429	0.2258
105	331.4	302.0	1187.2	885.2	4.230	0.2365
110	334.8	305.5	1188.0	882.5	4.047	0.2472
115	338.1	309.0	1188.8	879.8	3 880	0.2577
120	341.3	312.3	1189.6	877.2	3.726	0.2683
125	344.4	315.5	1190.3	874.7	3.583	0.2791
130	347.4	318.6	1191.0	872.3	3.452	0.2897
135	350.3	321.7	1191.6	869.9	3.331	0.3002
140	353.1	324.6	1192.2	867.6	3.219	0.3107
145	355.8	327.4	1192.8	865.4	3.112	0.3213
150	358.5	330.2	1193.4	863.2	3.012	0.3320
155	361.0	332.9	1194.0	861.0	2.920	0.3425
160	363.6	335.6	1194.5	858.8	2.834	0.3529
165	366.0	338.2	1195.0	856.8	2.753	0.3633
170	368.5	340.7	1195.4	854.7	2.675	0.3738
175	370.8	343.2	1195.9	852.7	2.602	0.3843
180	373.1	345.6	1196.4	850.8	2.533	0.3948
185	375.4	348.0	1196.8	848.4	2.468	0.4052
190	377.6	350.4	1197.3	846.9	2.406	0.4157
195	379.8	352.7	1197.7	845.0	2.346	0.4262
200	381.9	354.9	1198.1	843.2	2.290	0.437
205	384	357.1	1198.5	841.4	2.237	0.447
210	386	359.2	1198.8	839.6	2.187	0.457
215	388	361.4	1199.2	837.9	2.138	0.468
220	389.9	363.4	1199.6	836.2	2.091	0.478
225	391.9	365.5	1199.9	834.4	2.046	0.489
230	393.8	367.5	1200.2	832.1	2.004	0.499
235	395.6	369.4	1200.6	831.1	1.964	0.509
240	397.4	371.4	1200.9	829.5	1.924	0.520
245	399.3	373.3	1201.2	827.9	1.887	0.530
250	401.1	375.2	1201.5	826.3	1.850	0.541
260	404.1	378.9	1202.1	823.1	1.782	0.561
270	407.9	382.5	1202.6	820.1	1.718	0.582
280	411.2	386.0	1203.1	817.1	1.658	0.603
290	414.4	389.4	1203.6	814.2	1.602	0.624
300	417.5	392.7	1204.1	811.3	1.551	0.645
310	420.5	395.9	1204.5	808.5	1.502	0.666
320	423.4	399.1	1204.9	805.8	1.456	0.687
330	426.3	402.2	1205.3	803.1	1.413	0.708
340	429.1	405.3	1205.7	800.4	1.372	0.729
350	431.9	408.2	1206.1	797.8	1.334	0.750

TABLE I.—Continued.

Pressure in pounds, per square inch, absolute.	Temperature of boiling point, degrees Fahr.	Sensible heat of the liquid, above 32° Fahr.	Total heat of steam, above 32° Fahr.	Latent heat of evaporation.	Specific volume, cubic feet per pound.	Density pounds per cubic foot.
p.	*t.*	*h.*	*H.*	*L.*	*v.*	*1/v.*
360	434.6	411.2	1206.4	795.3	1.298	0.770
370	437.2	414.0	1206.8	792.8	1.264	0.791
380	439.8	416.8	1207.1	790.3	1.231	0.812
390	442.3	419.5	1207.4	787.9	1.200	0.833
400	444.8	422.0	1208.0	786.0	1.17	0.86
450	456.5	435.0	1209.0	774.0	1.04	0.96
500	467.3	448	1210.0	762.0	0.93	1.08
550	477.3	459	1210.0	751.0	0.83	1.20
600	486.6	469	1210.0	741.0	0.76	1.32

The pressures in this table are absolute pressures. Convert the corrected barometer reading into pounds per square inch, add this pressure to the gage pressure, and with this absolute pressure enter the table for the desired data.

Tables I and II are adapted from Marks & Davis' Steam Tables, by the kind permission of Professor Lionel S. Marks and Longmans Green & Co., publishers. Marks & Davis' Tables are now considered standard by the Bureau of Steam Engineering.

TABLE II.

Absolute pressures in inches of mercury.	Absolute pressures in pounds per square inch.	Temperature of boiling-point, degrees Fahr.	Sensible heat of the liquid above 32° Fahr.	Total heat above 32° Fahr.	Latent heat of evaporation.	Specific volume, cubic feet per pound.	Density, pounds per cubic foot.
			h.	*H.*	*L.*	*v.*	*1/v.*
.1804	0.0886	32	0.00	1073.4	1073.4	3294	.000304
.5	0.2463	58.9	26.98	1085.36	1058.36	1253.2	.000798
1.0	0.4909	79.1	47.14	1094.35	1047.24	654.98	.001528
1.5	0.7364	91.8	59.80	1100.00	1040.12	444.86	.002248
2.0	0.984	101.3	69.27	1104.15	1004.92	338.15	.002958
2.5	1.228	108.8	76.74	1107.42	1030.72	273.49	.003644
3.0	1.475	115.2	83.12	1110.28	1027.1	230.68	.004335
3.5	1.717	120.6	88.51	1112.60	1024.1	200.22	.005002
4.0	1.965	125.5	93.40	1114.75	1021.35	176.15	.005678
4.5	2.207	129.8	97.69	1116.60	1018.92	157.90	.006337
5.0	2.461	133.9	101.78	1118.36	1016.56	142.56	.00701
5.5	2.705	137.5	105.37	1119.90	1014.55	130.50	.00767
6.0	2.945	140.8	108.67	1121.32	1012.70	120.64	.00830
6.5	3.187	143.9	111.77	1122.66	1010.86	111.97	.00894
7.0	3.438	146.9	114.76	1123.96	1009.16	104.25	.00960
7.5	3.678	149.6	117.46	1125.10	1007.64	97.82	.01022
8.0	3.931	152.3	120.16	1126.22	1006.05	91.97	.01088
8.5	4.179	154.8	122.66	1127.32	1004.62	86.80	.01152
9.0	4.419	157.1	124.96	1128.24	1003.34	82.41	01214
9.5	4.670	159.4	127.26	1129.34	1001.96	78.22	.01279
10.0	4.909	161.5	129.36	1130.25	1000.80	74.65	.01340
10.5	5.159	163.6	131.46	1131.04	999.54	71.24	.01405
11.0	5.397	165.5	133.36	1131.40	998.45	68.35	.01464
11.5	5.655	167.5	135.36	1132.60	997.30	65.40	.01530
12.0	5.896	169.3	137.16	1133.42	996.22	62.91	.01590
12.5	6.145	171.1	138.97	1134.14	995.14	60.57	.01653
13.0	6.385	172.8	140.67	1134.82	994.12	58.36	.01714
14	6.883	176.1	143.87	1136.24	992.26	54.39	.01838
15	7.377	179.2	147.08	1137.50	990.38	52.09	.01961
16	7.867	182.1	149.99	1138.64	988.64	48.04	.02082
17	8.344	184.8	152.69	1139.72	987.02	45.43	.02201
18	8.836	187.4	155.30	1140.76	985.46	43.11	.02320
19	9.32	189.9	157.81	1141.76	983.96	41.19	.02442
20	9.82	192.4	160.31	1142.76	982.46	38.00	.02564
22	10.81	196.9	164.83	1144.56	979.76	35.69	.02793
24	11.79	201.1	169.04	1146.24	977.14	32.90	.03040
26	12.77	205.0	172.96	1147.4	974.7	30.53	.03276
28	13.77	208.7	176.06	1149.1	972.3	28.43	.03518
29.92	14.70	212.0	180.0	1150.4	970.4	26.79	.03732

With pressures less than atmospheric, subtract the vacuum in inches of mercury from the corrected barometer reading and with the remaining pressure in inches of mercury enter the table for the desired results.

TABLE I B.

OXYGEN AND AIR REQUIRED FOR THE COMBUSTION OF CARBON, HYDROGEN, ETC.

Element or substance burned.	Burned to—	Chemical reaction.	Combining weights.	Calculation.	Lbs. of O per lb. of substance.	Lbs. $NO \times 3.32$.	Air per lb. $4.32 \times O$.	Gases produced per lb.
C	CO_2	C+2O	12+32	32+12	$2\frac{2}{3}$	8.85	11.52	12.52
C	CO	C+O	12+16	16+12	$1\frac{1}{3}$	4.43	5.76	6.76
CO	CO_2	CO+O	28+16	16+28	$\frac{4}{7}$	1.90	2.47	3.47
H	H_2O	2H+O	2+16	16+2	8	25.76	34.56	35.56
C	CO_2 & $2H_2O$	C+4H+4O	16+64	64+16	4	13.28	17.28	18.28
S	SO_2	S+2O	32+32	32+32	1	3.32	4.32	5.32

DENSITIES OF GASES.*

Element or substance.	Symbol.	Specific gravity, air, 1.	Weight of 1 cubic foot.	Relative density, H, 1.	Relative density, approximate.
Oxygen	O	1.10521	.088843	15.96	16
Nitrogen	N	.9701	.078314	14.01	14
Hydrogen	H	.069234	.005589	1.	1
Carbon dioxide	CO_2	1.51968	.122681	21.95	22
Carbon monoxide	CO	.96709	.078071	13.97	14
Marsh gas (methane)	CH_4	.55297	.04464	7.99	8
Ethylene	C_2H_4	.96744	.07810	13.97	14
Acetylene	C_2H_2	.8982	.07301	12.97	13
Sulphur dioxide	SO_2	2.21295	.178646	31.96	32
Air	....	1.	.080728	.....	....

* The first column of figures is based on Hempels' Gas Analysis, and the second on the weight of air by Rankine, .080728 at 32° F. and at atmospheric pressure.

TABLE II B.

TEMPERATURE OF FIRE WHEN BURNING PURE CARBON WITH VARYING AMOUNTS OF AIR.

Heating value of carbon burned to CO_2, 14,600 B. T. U. per pound.
Heating value of carbon burned to CO, 4,450 B. T. U. per pound.
Specific heat of gases of combustion in either case, .24.
Formula: Elevation of temperature in degrees Fahr. =

$$\frac{\text{B. T. U. generated by combustion}}{\text{Weight of gases} \times \text{specific heat of gases}}$$

To burn 1 pound of C to CO_2 with no excess of air requires 11.52 pounds of air, making 12.52 pounds of gas.
To burn 1 pound of C to CO with no excess of air requires 5.76 pounds of air, making 6.76 pounds of gas.

PART I.—TEMPERATURES OF FIRE WITH AN INSUFFICIENT AMOUNT OF AIR.

Percentage of air below 11.52	0.0	10	20	30	40	50
Air per lb. of C	11.52	10.37	9.22	8.06	6.95	5.76
Air plus C per lb. of C=lbs. of gas	12.52	11.37	10.22	9.06	7.95	6.76
Percentage of C burned to CO_2	100	80	60	40	20	0.0
Percentage of C burned to CO	0.0	20	40	60	80	100
Heat (B.T.U.) generated in making CO_2	14,600	11,680	8,760	5,840	2,920	0.0
Heat (B.T.U.) generated in making CO	0.0	890	1,780	2,670	3,560	4,450
Total heat generated	14,600	12,570	10,540	8,510	6,480	4,450
Elevation of the temperature of the fire	4,860	4,606	4,298	3,914	3,418	2,748

PART II.—TEMPERATURES OF FIRE WITH AN EXCESS OF AIR. ALL C BURNED TO CO_2.

Percentage of air above 11.52 lbs. per lb. of C	25	50	75	100	150	200
Lbs. of air per lb. of carbon	14.40	17.28	20.16	23.04	28.80	34.56
Lbs. of air plus C per lb. of C = lbs. of gas	15.40	18.28	21.16	23.04	28.80	35.56
Percentage of C burned to CO_2	100	100	100	100	100	100
Heat (B.T.U.) generated in making CO_2	14,600	14,600	14,600	14,600	14,600	14,600
Elevation of the temperature of the fire	3,950	3,328	2,875	2,530	2,041	1,711

NOTE.—The temperatures of the fire given above are theoretical and are based on the assumption that there is no loss by radiation, convection or otherwise. They are never attained in practice, since the losses mentioned above are always present.

TABLE III.

SPECIFIC HEATS OF SOME GASES.

Substance.	Temperature range in degrees C.	Mean specific heat at constant pressure.
Air	20-440	.2366
	20-800	.2430
Carbon dioxide (CO_2)	15-100	.2025
	11-214	.2169
Carbon monoxide (CO)	26-198	.2426
Hydrogen	21-100	3.4100
Nitrogen	20-440	.2419
Oxygen	20-440	.2240
Sulphur dioxide (SO_2)	16-202	.1544
Water vapor	100	.421
	180	.51

TABLE IV.

SPECIFIC HEATS OF SOME LIQUIDS.

Substance.	Temperature range in degrees C.	Specific heat.
Alcohol	0	.548
(Methyl)	40	.648
Glycerine	15-50	.576
Oils—castor	20	.434
Turpentine	0	.411
Petroleum	21-58	.511

TABLE V.

SPECIFIC HEATS OF SOME SOLIDS.

Substance.	Temperature range in degrees C.	Specific heat.
Carbon—graphite	11	.16
Copper	17	.0924
Iron, cast	20-100	.1189
Iron, wrought	15-100	.1152
Lead	15	.0299
Mercury	85	.0328
Nickel	100	.1128

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